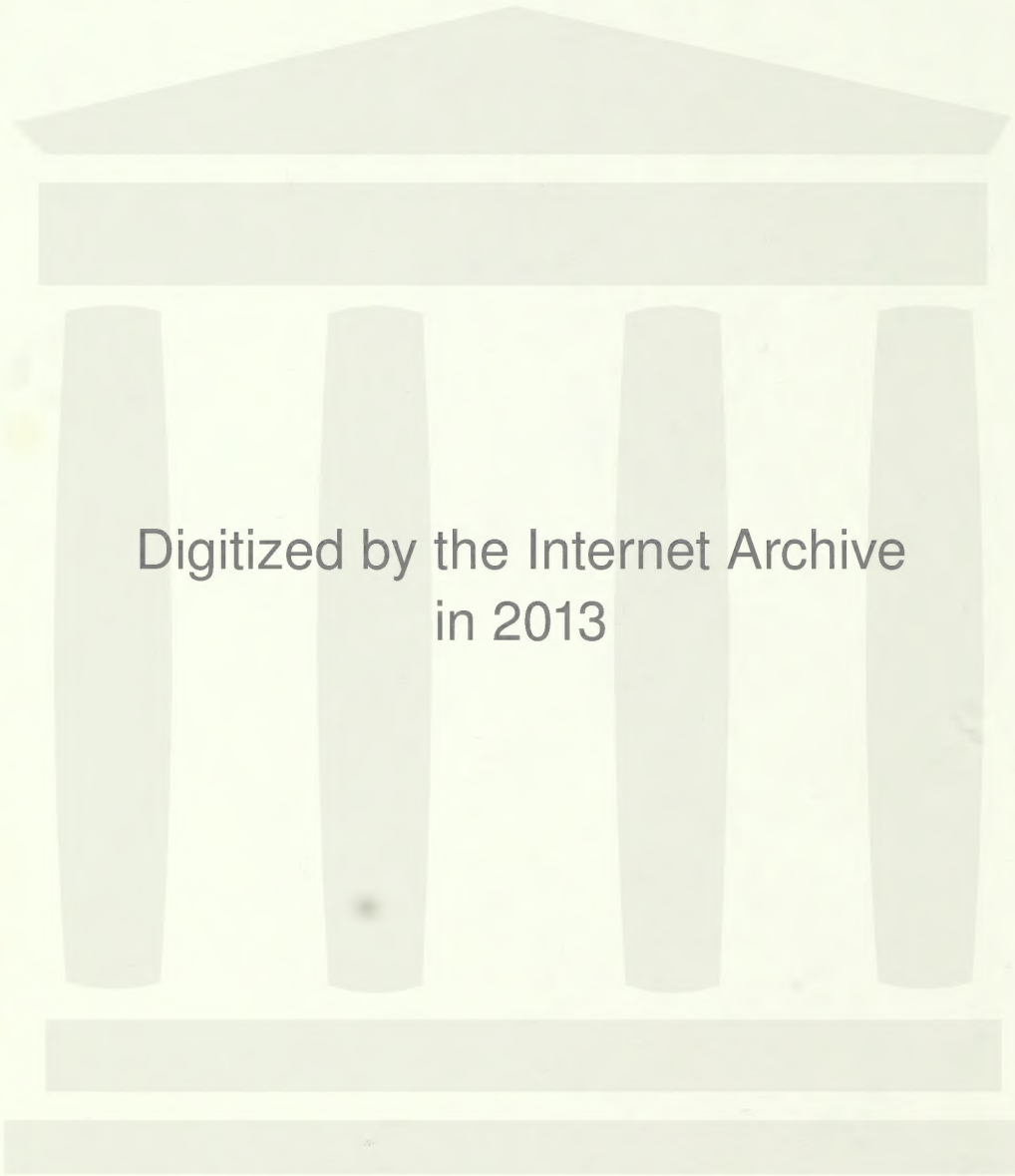

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Predicted Weights and Volumes of Scarlet Oak Trees on the Tennessee Cumberland Plateau

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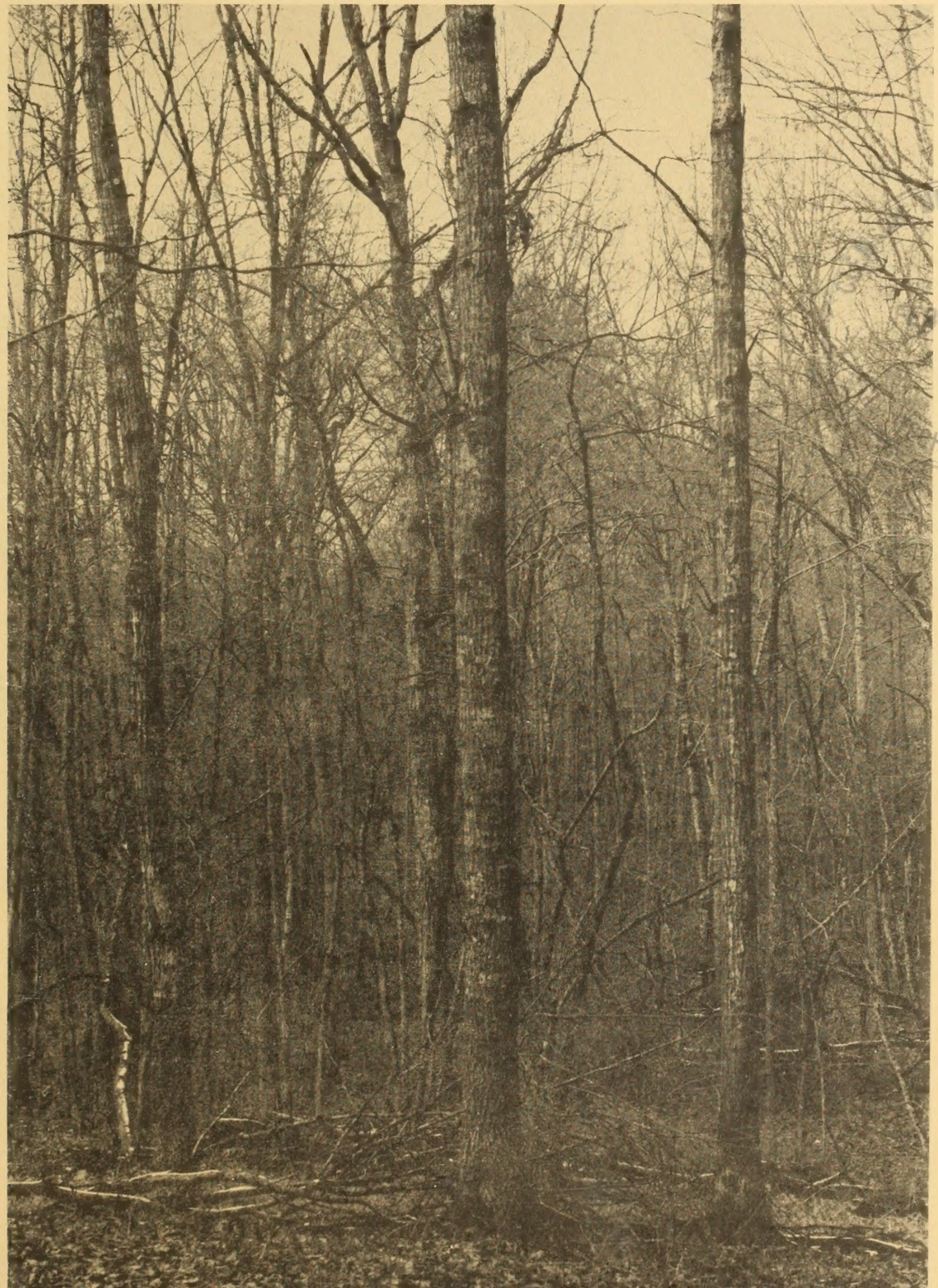
by Alexander Clark III, Douglas R. Phillips, and Harry C. Hitchcock III



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Conversion factors: English to metric

Multiply	*By*	*To obtain*
Inches	2.540	centimeters
Feet	.3048	meters
Pounds	.4536	kilograms
Cubic feet	.02832	cubic meters
Pounds per cubic foot	16.02	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor listed above.

August 1980
Southeastern Forest Experiment Station
Asheville, North Carolina

Predicted Weights and Volumes of Scarlet Oak Trees on the Tennessee Cumberland Plateau[1]

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ABSTRACT.—Total weights and volumes above stumps were determined for 28 scarlet oak (*Quercus coccinea* Muenchh.) trees 5 to 20 inches d.b.h. growing on the Tennessee Cumberland Plateau. Equations are presented for predicting green and dry weight and green volume of the total tree and its components using d.b.h. and total height, d.b.h. and height to a 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Tables developed from equations show weight and volume of the total tree and its components by d.b.h. and total height classes. Seventy-two percent of the average tree's green weight was in stem material to a 4-inch top, and 28 percent was in crown material. Total-tree wood had an average specific gravity of 0.608, average moisture content of 76 percent, and average green weight per cubic foot of 67 pounds. The weight of wood and bark averaged 79 pounds per cubic foot of wood for the total tree.

Keywords: *Quercus coccinea* Muenchh., biomass, component proportions, equations, specific gravity, moisture content, weight per cubic foot.

Forest trees are one of this country's most important renewable resources and must be utilized efficiently to meet increasing demands for solid wood, fiber, and energy. Utilizing the total tree above stump compared to utilizing only the merchantable saw-log stem can increase individual hardwood tree yields by 10 to 65 percent (Clark 1978). Equations for estimating the weight and volume of the total tree are needed to adequately evaluate and utilize scarlet oak (*Quercus coccinea* Muenchh.) trees. Wiant and others (1977) and Ford (1976) developed stem and total-tree weight equations for scarlet oaks in the northern Appalachian Mountains but not for scarlet oak in central Tennessee.

This Paper presents green volumes and green and dry weights of above stump biomass of commercial-size scarlet oaks growing in an uneven-aged stand in north-central Tennessee. Equations and yield tables predict weight and volume of the total tree and its components (wood, bark, saw logs, stem, and crown). Wood and bark specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its components.

PROCEDURE

FIELD

A stratified random sample of 28 scarlet oak trees was selected from a natural, closed, uneven-age stand of mixed oak with no evidence of fire

[1]This study was conducted in cooperation with and through the financial assistance of the Division of Forestry, Fisheries and Wildlife Development, Tennessee Valley Authority, Norris, Tennessee. Cooperation and assistance were also received from the Catoosa Wildlife Management Area personnel of the Tennessee Wildlife Resources Agency.

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damage. The stand sampled had an average site index of 70 and was located on the Catoosa Wildlife Management Area in Cumberland County, Tennessee. Two to four trees were selected from each two-inch d.b.h. class from 6 to 20 inches. Form class of the sawtimber trees sampled ranged from 77 to 83 and averaged 80. The trees sampled ranged from 37 to 80 years old and averaged 53 years old. Means and ranges of tree measurements are shown in table 1.

Table 1.—Means and ranges in dimensions of scarlet oak trees sampled in Cumberland County, Tennessee, by d.b.h. class

D.b.h. class (inches)	Sample trees	D.b.h.		Total height		Height to 4-inch d.i.b. top		Height to saw-log merchantable top[1]		D.o.b. at saw-log merchantable top	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Number	*Inches*		*Feet*						*Inches*	
6	4	5.9	5.1– 6.6	56	50–62	24	17–31	—	—	—	—
8	4	8.0	7.2– 8.5	64	58–70	38	35–42	—	—	—	—
10	4	10.1	9.1–10.9	68	62–73	43	37–51	—	—	—	—
12	4	12.0	11.5–12.3	69	62–75	46	42–52	22	13–25	9.7	9.1–10.6
14	4	14.2	13.2–14.8	82	73–87	57	50–62	31	21–45	11.3	10.2–12.7
16	4	15.9	15.0–16.8	86	80–94	63	59–68	34	27–40	12.2	11.5–12.8
18	2	17.5	17.1–17.9	87	83–90	66	63–69	34	27–41	13.4	12.9–13.9
20	2	19.7	19.3–20.0	84	84–84	65	64–66	30	26–34	15.0	15.0–15.1
All classes	28	12.1	5.1–20.0	73	50–94	48	17–69	29	13–45	12.5	9.1–15.1

[1]Height to 8-inch d.i.b. or saw-log merchantable top.

Trees were felled and limbed during the winter, and the main stem of each tree was bucked into merchantable saw logs and pulpwood. Saw logs 8 to 16 feet long were cut from the main stem to an 8-inch d.i.b. top or a degrading quality indicator such as large knots. Stem d.o.b. at a saw-log top averaged 12.5 inches (table 1). All material between the saw-log merchantable top and the 4-inch d.i.b. top was classed as "pulpwood," and material between the 4- and 2-inch d.i.b. top was classed as "topwood." The crown was cut up and separated into four categories: (1) extra large branches ($\geq$ 4.0 inches d.o.b.), (2) larger branches ($\geq$ 2.0 and $<$ 4.0 inches d.o.b.), (3) medium branches ($\geq$ 0.6 inches and $<$ 2.0 inches d.o.b.), (4) small branches ($\leq$ 0.5 inches d.o.b.). The tip of the stem (2 inches d.i.b. to top) was included as branch material in the analysis. Dead branches were cut from the bole and weighed separately. All crown material and pulpwood were weighed to the nearest quarter of a pound. Saw logs were weighed individually to the nearest pound.

Disks were removed from the butt of each sawtimber tree (trees $\geq$ 11.0 inches d.b.h.), at each saw-log bucking point, at the points where d.i.b. measured 8, 6, 4, and 2 inches, and from branches randomly selected from each branch-size category. In pulpwood-size trees (trees 5.0 to 10.9 inches d.b.h.), disks were cut from the butt of each tree, at quarter points to a 4-inch top, and where d.i.b. measured 2.0 inches. Each disk was sealed in a polyethylene bag for subsequent laboratory determination of moisture content, specific gravity, and bark percent.

LABORATORY

Specific gravity of each wood and bark sample was computed on a green volume and ovendry weight basis. Moisture content was computed on an ovendry basis after samples were dried to a constant weight at 103° C. Percentage of bark was determined from disks on a green weight basis. Moisture content, specific gravity, and percentage of bark in stem, branches, and total tree were calculated by weighting disk values in proportion to the volume of the component they represented. Weighted values for moisture content were used to convert component green weight to ovendry weight.

Green weight per cubic foot of wood and bark were calculated from weighted values for specific gravity and moisture content with the equation:

$$\text{Green weight per cubic foot} = [1 + \text{M.C.}/100] \times (\text{S.G.}) \times (C) \qquad (1)$$

where:

M.C. = weighted moisture content in percent
S.G. = weighted specific gravity
C = 62.4 pounds (weight of water per cubic foot)

Cubic-foot volumes of green wood and bark were computed by dividing component weight by its green weight per cubic foot. Green cubic-foot volume (wood and bark combined) was computed by adding the green volume of wood to the green volume of bark.

ANALYSIS

Linear regression equations were developed to predict green and dry weights and green volumes of wood and bark in the total tree and its components. Independent variables were: diameter at breast height (D), total height (Th), merchantable height (Mh), and height to a 4-inch top (H4), both separately and in various combinations. Grouping the data into D^2 and D^2Th Classes and plotting the variance of Y over D^2 and D^2Th indicated that the variance of predicted weights and volumes increased with increasing D^2 and D^2Th. A logarithmic transformation (to the base 10) was used to obtain a relatively homogeneous variance which is assumed in regression analysis. Thus, regression equations for tree and component weights and volumes were calculated using the equations:

$$\log Y = b_0 + b_1 \log X + \epsilon \quad (2)$$

$$\log Y = b_0 + b_1 \log X_1 + b_2 \log X_2 + \epsilon \quad (3)$$

where:

Y = weight or volume of component

X = D^2, D^2Th, D^2H4, or D^2Mh

$X_1 = D^2$

X_2 = Th, H4, or Mh

ϵ = sampling error

b_i = regression coefficients

When logarithmic estimates are converted back to original units they are biased downward because the antilogarithm of the estimated means gives the geometric rather than the arithmetic mean (Cunia 1964). To account for this bias, a correction factor was computed using a procedure described by Baskerville (1972) and applied to each equation. The forms of the equations, including the correction factor, are:

$$Y = 10^{b_0 + b_1 \log X + \frac{S^2_{y \cdot x}}{2}} \quad (4)$$

and

$$Y = 10^{b_0 + b_1 \log X_1 + b_2 \log X_2 + \frac{S^2_{y \cdot x}}{2}} \quad (5)$$

where:

$S^2_{y \cdot x}$ = error mean square from regression analysis

Equations (4) and (5) were simplified to:

$$Y = aX^{b_1} \quad (6)$$

and

$$Y = aX_1^{b_1} X_2^{b_2} \quad (7)$$

where:

$$a = 10^{b_0 + \frac{S^2_{y \cdot x}}{2}}$$

PROPERTIES OF SAMPLE TREES

TOTAL-TREE COMPONENTS

Green weight of the trees sampled ranged from 406 pounds for 6-inch trees to 6,547 pounds for 20-inch trees. Assuming the trees were composed solely of wood, bark, and water, 42 percent of their green weight was water; 48 percent was wood; and 10 percent was bark. The proportions of wood and bark in the total tree did not vary significantly with tree size. The proportions of total-tree weight in bark ranged from 15 to 17 percent, averaging 16 percent on a green basis. Wood made up an average of 83 percent of total-tree dry weight, and bark 17 percent.

The proportion of green weight in crown material (all live branches and topwood) ranged from 26 to 35 percent and did not vary consistently with tree size. The proportion of green weight in the stem to a 4-inch d.i.b. top averaged 72 percent and proportion in crowns averaged 28 percent. Seventy percent of the tree's dry weight was in stem material and 30 percent was in crown material.

The proportion of total-tree green weight in

dead branches ranged from 3 to 5 percent and did not vary with tree size. The proportion of dead branches averaged 3 percent on a green basis and 4 percent on a dry basis.

The green and dry weights of all wood and bark in the tree and the distribution of wood and bark throughout the tree are presented in tables 2 and 3. Sawtimber-size trees on the average had 74 percent of their green wood weight in the stem to a 4-inch top and 26 percent in the crown. Fifty-two percent of their green wood weight was saw-log material and 22 percent was pulpwood. Pulpwood-size trees had 72 percent of their total green wood weight in the stem to a 4-inch top and 28 percent crown.

Wood and bark are not distributed evenly throughout the tree. For example, the stem to a 4-inch top of the average pulpwood-size tree contained 72 percent of all the green wood in the tree but only 62 percent of the green bark. On the other hand, branches contained 17 percent of the green wood compared to 28 percent of the green bark. The proportion of green wood in branches increased with increasing tree size and ranged from 12 percent in 6-inch trees to 28 percent in 20-inch trees. The proportion of total-tree green bark weight in branches also increased with tree size, ranging from 22 percent in 6-inch trees to 45 percent in 20-inch trees.

STEM COMPONENTS

The main stem to a 4-inch top had 86 percent of its green weight in wood and 14 percent in bark,

Table 2.—Average green and dry weight of wood in the total tree and distribution of wood in main stem[1] and live branches in scarlet oak trees

D.b.h. class (inches)	Average total height	Sample trees	Total-tree wood weight	Proportion of wood in—								
				Main stem				Live branches (inches d.o.b.)				
				Saw log[2]	Pulp-wood[3]	Top-wood	Total stem	≥ 4	< 4 & ≥ 2	< 2 & > 0.5	≤ 0.5	All branches
	Feet	*Number*	*Pounds*	..... *Percent*								
				GREEN PULPWOOD								
6	56	4	340	—	67	21	88	—	0	9	3	12
8	64	4	680	—	74	8	82	—	4	11	3	18
10	68	4	1,250	—	75	4	79	—	8	10	3	21
Average	—	—	757	—	72	11	83	—	4	10	3	17
				GREEN SAWTIMBER								
12	69	4	1,871	44	29	2	75	2	10	11	2	25
14	82	4	3,072	52	22	1	75	7	9	8	1	25
16	86	4	3,807	56	18	1	75	9	8	6	2	25
18	87	2	4,763	54	21	1	76	9	8	5	2	24
20	84	2	5,475	51	21	[4]0	72	10	9	7	2	28
Average	—	—	3,468	52	22	1	75	7	9	7	2	25
				DRY PULPWOOD								
6	56	4	194	—	65	22	87	—	0	10	3	13
8	64	4	395	—	73	8	81	—	4	11	4	19
10	68	4	711	—	74	4	77	—	9	11	3	23
Average	—	—	433	—	71	11	82	—	4	11	3	18
				DRY SAWTIMBER								
12	69	4	1,078	43	28	2	73	2	10	13	2	27
14	82	4	1,754	50	22	1	73	8	9	9	1	27
16	86	4	2,130	54	18	1	73	9	9	7	2	27
18	87	2	2,696	53	20	1	74	9	9	6	2	26
20	84	2	3,006	49	20	[4]0	69	10	11	8	2	31
Average	—	—	1,953	50	21	1	72	8	10	8	2	28

[1]Main stem to 2-inch d.i.b. top.
[2]Saw logs to 8-inch d.i.b. or saw-log merchantable top.
[3]Pulpwood in stem from butt or saw-log top to 4-inch d.i.b. top.
[4]Less than one-half of one percent.

Table 3.—Average green and dry weight of bark in the total tree and distribution of bark in main stem[1] and live branches in scarlet oak trees sampled

D.b.h. class (inches)	Average total height	Sample trees	Total-tree bark weight	Proportion of bark in—								
				Main stem				Live branches (inches d.o.b.)				
				Saw log[2]	Pulp-wood[3]	Top-wood	Total stem	≥ 4	< 4 & ≥ 2	< 2 & > 0.5	≤ 0.5	All branches
	Feet	*Number*	*Pounds*	..... *Percent*								
				GREEN PULPWOOD								
6	56	4	66	—	57	21	78	—	0	16	6	22
8	64	4	136	—	62	7	69	—	4	18	9	31
10	68	4	238	—	67	3	70	—	11	13	6	30
Average	—	—	146	—	62	10	72	—	5	16	7	28
				GREEN SAWTIMBER								
12	69	4	360	37	24	2	63	3	12	17	5	37
14	82	4	541	41	19	1	61	9	11	14	5	39
16	86	4	718	45	17	1	63	11	11	11	4	37
18	87	2	860	45	18	1	64	11	11	11	3	36
20	84	2	1,072	38	16	1	55	12	13	14	6	45
Average	—	—	646	42	18	1	61	9	12	13	5	39
				DRY PULPWOOD								
6	56	4	41	—	58	21	79	—	0	15	6	21
8	64	4	86	—	63	8	71	—	4	17	8	29
10	68	4	151	—	67	3	70	—	11	13	6	30
Average	—	—	93	—	63	10	73	—	5	15	7	27
				DRY SAWTIMBER								
12	69	4	227	37	25	2	64	3	12	17	4	36
14	82	4	340	41	18	2	61	9	11	14	5	39
16	86	4	451	46	16	1	63	11	11	11	4	37
18	87	2	540	44	18	1	63	11	12	11	3	37
20	84	2	666	39	16	1	56	12	13	13	6	44
Average	—	—	405	42	18	1	61	9	12	13	5	39

[1]Main stem to 2-inch d.i.b. top.
[2]Saw logs to 8-inch d.i.b. or saw-log merchantable top.
[3]Pulpwood in stem from butt or saw-log top to 4-inch d.i.b. top.

while 85 percent of the dry stem weight was wood and 15 percent bark. The proportion of stem weight in wood and bark did not vary significantly with tree size.

CROWN COMPONENTS

The proportion of crown green weight in bark ranged from 20 to 24 percent but did not vary with tree size. The proportion of crown weight in wood averaged 78 percent and in bark it averaged 22 percent on both the green and dry bases. For branches, the proportion of green weight in bark increased with decreasing branch size. Branches ≥ 4 inches d.o.b. had 20 percent of their green weight in bark, while branches ≤ 0.5 inches d.o.b. had 32 percent of their green weight in bark.

Dead branches composed 11 percent of crown green weight and 13 percent of crown dry weight.

The change in distribution of crown materials with increasing tree size is shown in figure 1.

PHYSICAL PROPERTIES

Wood and bark specific gravity, moisture content, and green weight per cubic foot for the total tree and its components are presented in table 4. Wood specific gravity and moisture content did not vary significantly with tree size. Wood specific gravity averaged 0.608 for the total tree and 0.595 for the total stem—the same as the value (0.60) reported for the species (Forest Products Laboratory 1974). Branches had the

Table 4.—Average wood and bark specific gravity, moisture content, and green weight per cubic foot for scarlet oak trees and tree components

Tree component	Average and standard deviation		
	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	*Pounds*
WOOD			
Total tree	0.608 ± 0.022	76 ± 4.4	67 ± 1.5
Stem (butt to 4-inch d.i.b. top)	.595 ± .024	80 ± 5.4	67 ± 1.7
Saw log (butt to 8-inch d.i.b. top)	.592 ± .028	83 ± 5.1	68 ± 2.2
Pulpwood (8- to 4-inch d.i.b. top)	.618 ± .026	67 ± 4.8	67 ± 1.9
Topwood (4- to 2-inch d.i.b. top)	.630 ± .027	68 ± 4.8	66 ± 1.9
Branches	.648 ± .027	62 ± 3.2	66 ± 2.4
BARK			
Total tree	0.611 ± 0.027	59 ± 3.1	61 ± 2.7
Stem (butt to 4-inch d.i.b. top)	.629 ± .031	57 ± 4.0	62 ± 2.7
Saw log (butt to 8-inch d.i.b. top)	.624 ± .036	58 ± 4.6	61 ± 3.2
Pulpwood (8- to 4-inch d.i.b. top)	.643 ± .033	56 ± 3.5	63 ± 3.1
Topwood (4- to 2-inch d.i.b. top)	.629 ± .041	58 ± 5.6	62 ± 3.4
Branches	.572 ± .045	62 ± 5.9	58 ± 4.5

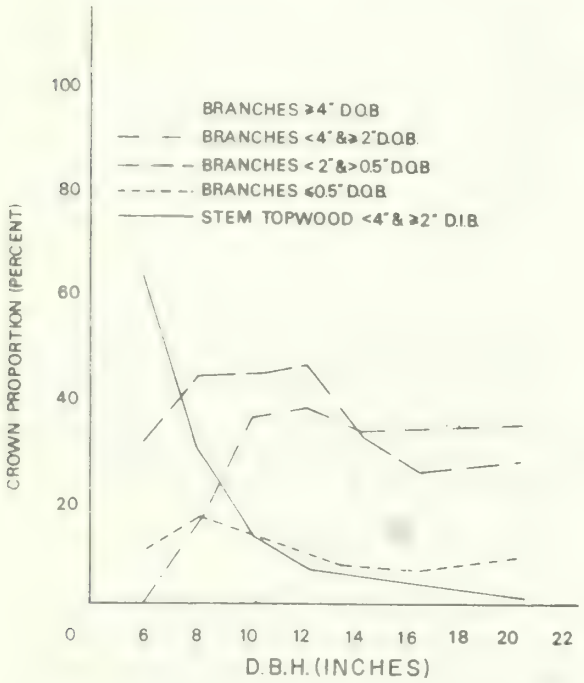

Figure 1.—Proportion of scarlet oak crown weight in topwood and branches, by branch d.o.b. size classes.

highest wood specific gravity, averaging 0.648, and saw-log wood the lowest, averaging 0.592. Average moisture content of wood ranged from 62 percent in the branches to 83 percent in saw logs and averaged 76 percent for all wood in the tree. Green weight per cubic foot of wood averaged 66 pounds in the branches and 67 pounds in the main stem and total tree.

Specific gravity of bark was lowest in branches (0.572) and highest in the pulpwood section of the main stem (0.643). Bark specific gravity in the total tree averaged 0.611—higher than wood specific gravity. Bark moisture content for the total tree averaged 59 percent, which was lower than the corresponding value for wood. Branch bark moisture content was highest, averaging 62 percent, and pulpwood bark was the lowest, averaging 56 percent. Average green bark weight per cubic foot ranged from 58 pounds for branches to 63 pounds for the pulpwood section and averaged 61 pounds for the total tree.

The weight of wood and bark per unit volume of wood is a useful factor for estimating the volume of wood in a tree or its components when weight with bark is known. The average green weight of wood and bark per cubic foot of wood was 79 pounds for the total tree and 78 pounds for the stem (table 5). For branch material, the green weight of wood and bark per cubic foot of wood averaged 84 pounds and was considerably higher than the average for the main stem because

branches contain 36 percent more of their weight in bark.

Green weight per cubic foot of wood and bark combined averaged 66 pounds for the total tree and stem, and 64 pounds for branch material (table 5).

higher coefficients of determination and slightly lower standard errors of estimates than the equations using D^2, D^2H4, or $D^2 + Mh$.

Equations using $D^2 + Mh$ were the best estimators of saw-log merchantable stem weight and volume, while equations using D^2H4 were the

Table 5.—Average green weight of wood and bark per cubic foot of wood and average green weight of wood and bark per cubic foot of wood and bark for scarlet oak trees and tree components

Tree component	Average and standard deviation	
	Green weight of wood & bark per cubic foot of wood	Green weight of wood & bark per cubic foot of wood & bark
	Pounds	
Total tree	79 ± 1.7	66 ± 1.4
Stem (butt to 4-inch d.i.b. top)	78 ± 2.3	66 ± 1.4
Saw log (butt to 8-inch d.i.b. top)	77 ± 2.7	67 ± 1.7
Pulpwood (8- to 4-inch d.i.b. top)	79 ± 3.3	66 ± 1.8
Topwood (4- to 2-inch d.i.b. top)	82 ± 3.4	65 ± 1.6
Branches	84 ± 3.0	64 ± 2.6

PREDICTION EQUATIONS

A series of equations was developed to predict weights and volumes of total trees and their components. Since heights of trees are measured to different top limits by various organizations, equations were developed using D^2 alone and in combination with Th, H4, and Mh separately and combined as independent variables. When D^2 and Th or D^2 and H4 were used, the one-variable equation (2) and the two-variable equations (3) predicted total-tree and component weights and volumes equally well. The use of height as a separate variable did not improve the coefficient of determination or reduce the standard error. Thus, the single-variable model was used to predict tree weight and volume when using D^2, D^2Th, and D^2H4 as the independent variable. When D^2 and Mh were used as separate variables in equation (3), the coefficient of determination (R^2) increased 15 to 20 percent and the standard error was reduced. Thus, the two-variable model was used when D^2 and Mh were the independent variables.

All independent variable combinations were good predictors of weights and volumes, but equations using D^2Th were the best for total-tree weight and volume. These equations had slightly

best predictors of stem weight and volume to a 4-inch top. When average tree heights and stem taper for d.b.h. classes are similar to those of our sample trees, the equations using d.b.h. alone will result in good estimates of tree weight and volume. However, when average tree heights by d.b.h. classes are different, the equations that include a height variable should be applied directly or used to develop local weight-volume tables based on d.b.h. alone.

Appendix tables 6 and 7 present equations for predicting all weights and volumes measured from D^2Th. Appendix tables 8 and 9 present equations that use D^2, D^2H4, and $D^2 + Mh$ to predict the green weights of wood and bark and volumes of wood for selected tree components of greatest interest. The Appendix also describes a method for placing confidence limits on predictions made with the equations.

A complete list of equations based on D^2, D^2H4, and D^2Mh for predicting the green and dry weights and volumes of wood and bark in all tree components listed in tables 6 and 7 is available from the authors at the Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Carlton Street, Athens, Georgia 30602. Also available are uncorrected sums and sums of squares and their cross products for the inde-

pendent and dependent variables listed in tables 6 and 7. These data make it possible to compare and combine equations statistically. They also allow for the addition of observations and for computation of error terms.

BIOMASS TABLES

Equations based on D^2Th from tables 6 and 7 were used to develop tables of biomass weight and volume. Tables 10–13 show predicted green weights of wood and bark and wood alone in the total tree, the saw-log stem to an 8-inch d.i.b. or saw-log merchantable top, the stem to a 4-inch d.i.b. top, and the crown. Tables 14–17 show predicted green volumes of wood and bark and wood alone in the the total tree and its components. The predicted weight or volume of bark in a tree or component can be estimated by subtracting the value in the table for wood alone from the corresponding value in the table for wood and bark combined.

Similar-sized trees may vary in weight and volume because of differences in crown size, stem taper, and weight per cubic foot. Therefore, the equations and tables should be applied only to trees growing in natural, fully stocked stands that have stem taper rates and weights per cubic foot similar to the trees sampled.

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COMPUTATION OF CONFIDENCE LIMITS

Tables 6, 7, 8, and 9 contain the standard errors of the estimate, the sample mean of x, and the corrected sums of squares for x for each equation in $\log_{10}$ form. These statistics can be used to calculate approximate confidence limits in pounds or cubic feet using a modification of Cox's formula (Land 1972) for estimating confidence limits for lognormal means:

$$Y_{U,L} = 10^{\log Y \pm Z \sqrt{S^2_{y \cdot x}\left[\frac{1}{n} + \frac{(x - \bar{x})^2}{\Sigma(x - \bar{x})^2}\right] + \frac{S^4_{y \cdot x}}{2(n-1)}}} \quad (8)$$

where:

$Y_{U,L}$ = upper and lower limits for Y,
Y = predicted weight or volume of component from equation (6),
Z = value from the standard normal table for appropriate confidence level,
$S_{y \cdot x}$ = standard error of estimate for prediction equation,
n = number of observations used to develop equation,
$\bar{x}$ = sample mean of log x — (from table of equations),
$\Sigma(x - \bar{x})^2$ = corrected sums of squares for log x — (from table of equations),
x = value of independent variable in $\log_{10}$ form.

Cox's method of approximation sufficiently estimates actual confidence limits when applied to samples with small variances as occur in the total tree and stem weight and volume of scarlet oak data sets. Thus, equation (8) should be used to approximate confidence limits for the single-variable equations presented in this Paper.

Appendix

Table 6.—Regression equations for estimating above-stump green and dry weight of the total tree and its components for scarlet oak trees 5 to 20 inches d.b.h. using d.b.h. and total height as independent variables

Weight (Y)	Regression equation[a]	Coefficient of determination (R^2)	Standard error[b] ($S_{y \cdot x}$)[c]	Number trees sampled (N)
Total tree (excluding foliage):				
Green weight	$Y = 0.19275\ (D^2Th)^{1.00974}$	0.99	0.0335	28
Dry weight	$Y = 0.12161\ (D^2Th)^{1.00031}$	.99	.0376	28
All wood in tree:				
Green weight	$Y = 0.15519\ (D^2Th)^{1.01440}$	.99	.0357	28
Dry weight	$Y = 0.09706\ (D^2Th)^{1.00409}$	.99	.0412	28
All bark in tree:				
Green weight	$Y = 0.03789\ (D^2Th)^{0.98688}$	.99	.0424	28
Dry weight	$Y = 0.02451\ (D^2Th)^{0.98391}$	.99	.0434	28
Wood and bark in stem from stump to saw-log merchantable top (trees ≥ 11.0 inches d.b.h.):				
Green weight	$Y = 0.06044\ (D^2Th)^{1.05689}$	.85	.0856	16
Dry weight	$Y = 0.04640\ (D^2Th)^{1.02407}$	.85	.0831	16
Wood in stem from stump to saw-log merchantable top (trees ≥ 11.0 inches d.b.h.):				
Green weight	$Y = 0.04863\ (D^2Th)^{1.06485}$	.86	.0850	16
Dry weight	$Y = 0.03753\ (D^2Th)^{1.02940}$	.86	.0817	16
Bark in stem from stump to saw-log merchantable top (trees ≥ 11.0 inches d.b.h.):				
Green weight	$Y = 0.01304\ (D^2Th)^{1.00505}$	.81	.0948	16
Dry weight	$Y = 0.00903\ (D^2Th)^{0.99591}$	.80	.0979	16
Wood and bark in stem from stump to 8-inch d.i.b. top (trees ≥ 11.0 inches d.b.h.):				
Green weight	$Y = 0.09738\ (D^2Th)^{1.03686}$	.98	.0313	16
Dry weight	$Y = 0.07483\ (D^2Th)^{1.00404}$	.97	.0349	16
Wood in stem from stump to 8-inch d.i.b. top (trees ≥ 11.0 inches d.b.h.):				
Green weight	$Y = 0.07837\ (D^2Th)^{1.04482}$	.98	.0314	16
Dry weight	$Y = 0.06054\ (D^2Th)^{1.00937}$	.97	.0362	16
Bark in stem from stump to 8-inch d.i.b. top (trees ≥ 11.0 inches d.b.h.):				
Green weight	$Y = 0.02099\ (D^2Th)^{0.98502}$	.95	.0441	16
Dry weight	$Y = 0.01452\ (D^2Th)^{0.97588}$	.95	.0453	16
Wood and bark in stem from stump to 4-inch d.i.b. top:				
Green weight	$Y = 0.09079\ (D^2Th)^{1.05414}$	.99	.0437	28
Dry weight	$Y = 0.05905\ (D^2Th)^{1.03882}$	.99	.0478	28
Wood in stem from stump to 4-inch d.i.b. top:				
Green weight	$Y = 0.07333\ (D^2Th)^{1.06140}$	.99	.0444	28
Dry weight	$Y = 0.04678\ (D^2Th)^{1.04597}$	.99	.0504	28

Continued

Table 6.—Regression equations for estimating above-stump green and dry weight of the total tree and its components for scarlet oak trees 5 to 20 inches d.b.h. using d.b.h. and total height as independent variables—Continued

Weight (Y)	Regression equation[a]	Coefficient of determination (R^2)	Standard error[b] ($S_{y \cdot x}$)[c]	Number trees sampled (N)
Bark in stem from stump to 4-inch d.i.b. top:				
Green weight	$Y = 0.01857\ (D^2Th)^{1.00981}$	.98	.0576	28
Dry weight	$Y = 0.01278\ (D^2Th)^{1.00135}$	.98	.0567	28
Wood and bark in crown (all branches and topwood < 4 inches d.i.b.):				
Green weight	$Y = 0.10793\ (D^2Th)^{0.93721}$	.95	.0916	28
Dry weight	$Y = 0.06122\ (D^2Th)^{0.94560}$	.95	.0921	28
Wood in crown (all branches and topwood < 4 inches d.i.b):				
Green weight	$Y = 0.09108\ (D^2Th)^{0.92903}$	.94	.0959	28
Dry weight	$Y = 0.05135\ (D^2Th)^{0.93779}$	.94	.0958	28
Bark in crown (all branches and topwood < 4 inches d.i.b):				
Green weight	$Y = 0.01706\ (D^2Th)^{0.97136}$	.95	.0945	28
Dry weight	$Y = 0.01004\ (D^2Th)^{0.97688}$	.95	.0954	28
Wood and bark in crown ≥ 2 inches d.o.b.:				
Green weight	$Y = 0.02185\ (D^2Th)^{1.04830}$	.86	.1695	28
Dry weight	$Y = 0.01186\ (D^2Th)^{1.06012}$	.87	.1661	28
Wood in crown ≥ 2.0 inches d.o.b.:				
Green weight	$Y = 0.02021\ (D^2Th)^{1.03447}$	.86	.1723	28
Dry weight	$Y = 0.01058\ (D^2Th)^{1.04924}$	.87	.1688	28
Bark in crown ≥ 2.0 inches d.o.b.:				
Green weight	$Y = 0.00220\ (D^2Th)^{1.11432}$	.88	.1646	28
Dry weight	$Y = 0.00144\ (D^2Th)^{1.10983}$	.88	.1644	28
Wood and bark in dead branches				
Green weight	$Y = 0.00495\ (D^2Th)^{1.03807}$	.87	.1618	28
Dry weight	$Y = 0.00480\ (D^2Th)^{1.01072}$	.85	.1737	28

[a] $Y = b_0(D^2Th)^{b_1}$

where:

Y = component weight in pounds,
D = d.b.h. in inches,
Th = Total tree height in feet,
b_0 and b_1 = regression coefficients.

[b] Standard error in $\log_{10}$ form.

[c] Additional statistics for computation of confidence intervals:

$\Sigma(x-\bar{x})^2 = 4.3559$ and $\bar{x} = 3.9631$ for equations based on 28 trees, and
$\Sigma(x-\bar{x})^2 = 0.5386$ and $\bar{x} = 4.2520$ for equations based on 16 trees.

Table 7.—Regression equations for estimating above-stump green cubic-foot volume of the total tree and its components for scarlet oak trees 5 to 20 inches d.b.h. using d.b.h. and total height as independent variables

Cubic-foot volume (Y)	Regression equation[a]	Coefficient of determination (R^2)	Standard error[b] ($S_{y \cdot x}$)[c]	Number trees sampled (N)
Total tree (excluding foliage):				
Wood	$Y = 0.00233\ (D^2Th)^{1.01465}$	0.99	0.0353	28
Bark	$Y = 0.00086\ (D^2Th)^{0.95266}$	.99	.0439	28
Wood & bark	$Y = 0.00311\ (D^2Th)^{1.00368}$	.99	.0335	28
Stem from stump to saw log merchantable top (trees ≥ 11.0 inches d.b.h.):				
Wood	$Y = 0.00054\ (D^2Th)^{1.09480}$	.87	.0824	16
Bark	$Y = 0.00027\ (D^2Th)^{0.97983}$	.80	.0966	16
Wood & bark	$Y = 0.00074\ (D^2Th)^{1.07831}$	.87	.0834	16
Stem from stump to 8-inch d.i.b. top (trees ≥ 11.0 inches d.b.h.):				
Wood	$Y = 0.00087\ (D^2Th)^{1.07477}$	.98	.0336	16
Bark	$Y = 0.00043\ (D^2Th)^{0.95980}$	.95	.0414	16
Wood & bark	$Y = 0.00119\ (D^2Th)^{1.05828}$	.98	.0317	16
Stem from stump to 4-inch d.i.b. top:				
Wood	$Y = 0.00104\ (D^2Th)^{1.06736}$	.99	.0419	28
Bark	$Y = 0.00040\ (D^2Th)^{0.97815}$	.98	.0569	28
Wood & bark	$Y = 0.00137\ (D^2Th)^{1.05401}$	.99	.0413	28
Crown (all branches and topwood < 4 inches d.i.b. excluding foliage):				
Wood	$Y = 0.00153\ (D^2Th)^{0.91833}$	.94	.0972	28
Bark	$Y = 0.00040\ (D^2Th)^{0.93593}$	.94	.1004	28
Wood & bark	$Y = 0.00194\ (D^2Th)^{0.92165}$	.94	.0941	28
Crown material ≥ 2.0 inches d.o.b.:				
Wood	$Y = 0.00033\ (D^2Th)^{1.02852}$	.86	.1720	28
Bark	$Y = 0.00005\ (D^2Th)^{1.08727}$	.88	.1672	28
Wood & bark	$Y = 0.00037\ (D^2Th)^{1.03921}$	.86	.1699	28
Dead branch material:				
Wood & bark	$Y = 0.00014\ (D^2Th)^{1.01008}$	.84	.1817	28

[a] $Y = b_0(D^2Th)^{b_1}$

where:

Y = component volume in cubic feet,
D = d.b.h. in inches,
Th = total tree height in feet,
b_0 and b_1 = regression coefficients.

[b] Standard error of estimates in $\log_{10}$ form.

[c] Additional statistics for computation of confidence intervals:

$\Sigma(x-\bar{x})^2 = 4.3559$ and $\bar{x} = 3.9631$ for equations based on 28 trees, and
$\Sigma(x-\bar{x})^2 = 0.5386$ and $\bar{x} = 4.4520$ for equations based on 16 trees.

Table 8.—Regression equations for estimating the above-stump wood and bark green weight for scarlet oak trees 5 to 20 inches d.b.h. and tree component parts using d.b.h., d.b.h. and height to 4-inch top, and d.b.h. and saw-log merchantable height as independent variables

Weight (Y)	Regression equation[a]	Coefficient of determination (R^2)	Standard error[b] ($S_{y \cdot x}$)	Sample mean of x^b ($\bar{x}$)	Corrected sums of squares for x^b $\Sigma(x - \bar{x})$	Number trees sampled (N)
Wood and bark in total tree above stump						
	$Y = 5.40549\,(D^2)^{1.21189}$	0.99	0.0411	2.1076	3.0139	28
	$Y = 1.36696\,(D^2H4)^{0.83664}$	.98	.0512	3.7671	6.2893	28
	$Y = 7.89942\,(D^2)^{1.14430}\,(Mh)^{-0.00098}$	.96	.0396	—	—	16
Wood and bark in stem from stump to saw-log merchantable top						
	$Y = 1.53071\,(D^2)^{1.31601}$	.83	.0923	2.3487	0.3377	16
	$Y = 0.24149\,(D^2H4)^{0.94792}$	.86	.0848	4.1060	0.6715	16
	$Y = 0.72165\,(D^2)^{0.96023}\,(Mh)^{0.79487}$	.99	.0171	—	—	16
Wood and bark in stem from stump to 4-inch d.i.b. top						
	$Y = 2.94471\,(D^2)^{1.26540}$	.99	.0497	2.1076	3.0139	28
	$Y = 0.66554\,(D^2H4)^{0.87923}$	.99	.0329	3.7671	6.2893	28
	$Y = 5.41150\,(D^2)^{1.09545}\,(Mh)^{0.09157}$	.95	.0408	—	—	16
Wood and bark in crown (all branches and top-wood < 4 inches d.i.b.)						
	$Y = 2.36491\,(D^2)^{1.12626}$	.94	.0922	2.1076	3.0139	28
	$Y = 0.72649\,(D^2H4)^{0.76682}$	.91	.1154	3.7671	6.2893	28
	$Y = 2.58978\,(D^2)^{1.26409}\,(Mh)^{-0.23979}$	.91	.0588	—	—	16

[a] $Y = a(D^2)^{b_1}$ or $Y = a(D^2H4)^{b_2}$ or $Y = a(D^2)^{b_1}(Mh)^{b_2}$.

where:

Y = component weight in pounds,
D = d.b.h. in inches,
H4 = tree height to 4-inch d.i.b. top in feet,
Mh = saw-log merchantable height in feet,
a, b_1, b_2 = regression coefficients.

[b] $\log_{10}$ form.

Table 9.—Regression equations for estimating the above-stump wood volume for scarlet oak trees 5 to 20 inches d.b.h. and tree component parts using d.b.h., d.b.h. and height to 4-inch top, and d.b.h. and saw-log merchantable height as independent variables

Cubic-foot volume (Y)	Regression equation[a]	Coefficient of determination (R^2)	Standard error[b] ($S_{y \cdot x}$)	Sample mean of x^b ($\bar{x}$)	Corrected sums of squares for x^b $\Sigma(x - \bar{x})^2$	Number trees sampled (N)
Wood in total tree above stump						
	$Y = 0.06656\ (D^2)^{1.21701}$	0.99	0.0452	2.1076	3.0139	28
	$Y = 0.01674\ (D^2H4)^{0.84014}$	.98	.0547	3.7671	6.2893	28
	$Y = 0.08866\ (D^2)^{1.18273}\ (Mh)^{-0.02745}$	.95	.0447	—	—	16
Wood in stem from stump to saw-log merchantable top						
	$Y = 0.01580\ (D^2)^{1.35893}$	.84	.0914	2.3487	0.3377	16
	$Y = 0.00230\ (D^2H4)^{0.98075}$	.87	.0823	4.1060	0.6715	16
	$Y = 0.00760\ (D^2)^{1.01280}\ (Mh)^{0.77330}$	.99	.0244	—	—	16
Wood in stem from stump to 4-inch d.i.b. top						
	$Y = 0.03530\ (D^2)^{1.28039}$	.99	.0509	2.1076	3.0139	28
	$Y = 0.00784\ (D^2H4)^{0.88967}$	.99	.0341	3.7671	6.2893	28
	$Y = 0.05793\ (D^2)^{1.14656}\ (Mh)^{0.06683}$	.94	.0466	—	—	16
Wood in crown (all branches and top-wood < 4 inches d.i.b.)						
	$Y = 0.03148\ (D^2)^{1.103612}$	.94	.0977	2.1076	3.0139	28
	$Y = 0.01001\ (D^2H4)^{0.75024}$	.90	.1208	3.7671	6.2893	28
	$Y = 0.03349\ (D^2)^{1.28174}\ (Mh)^{-0.29670}$	.91	.0578	—	—	16

[a] $Y = a(D^2)^{b_1}$ or $Y = a(D^2H4)^{b_2}$ or $Y = a(D^2)^{b_1}(Mh)^{b_2}$.

where:

Y = component volume in cubic feet,
D = d.b.h. in inches,
H4 = tree height to 4-inch d.i.b. top in feet,
Mh = saw-log merchantable height in feet,
a, b_1, b_2 = regression coefficients.

[b] $\log_{10}$ form.

Table 10.—Predicted green weight of above-stump total-tree wood and bark for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)						
	40	50	60	70	80	90	100
	Pounds						
	WOOD AND BARK[3]						
5	206	258	310	363	415		
6	298	373	449	524	600		
7	407	510	613	716	819		
8	533	667	802	937	1,073	1,208	
9	676	846	1,018	1,189	1,361	1,532	
10	836	1,047	1,259	1,471	1,683	1,896	2,109
11	1,013	1,269	1,526	1,783	2,040	2,298	2,556
12	1,208	1,513	1,819	2,126	2,432	2,740	3,047
13	1,420	1,779	2,138	2,498	2,859	3,220	3,582
14		2,066	2,484	2,902	3,321	3,740	4,160
15		2,375	2,855	3,336	3,817	4,299	4,782
16		2,705	3,252	3,800	4,348	4,898	5,447
17		3,058	3,676	4,295	4,915	5,536	6,157
18			4,126	4,820	5,516	6,213	6,910
19			4,602	5,377	6,153	6,930	7,708
20			5,104	5,963	6,824	7,686	8,549
21			5,632	6,581	7,531	8,482	9,434
22			6,187	7,229	8,273	9,317	10,363
	WOOD[4]						
5	171	215	259	302	346		
6	248	311	374	438	501		
7	339	425	512	599	685		
8	445	558	671	785	899	1,013	
9	565	708	852	997	1,141	1,286	
10	700	877	1,055	1,234	1,413	1,592	1,772
11	849	1,064	1,281	1,497	1,714	1,932	2,150
12	1,013	1,270	1,528	1,786	2,045	2,305	2,565
13	1,191	1,494	1,797	2,101	2,406	2,712	3,017
14		1,736	2,089	2,442	2,797	3,151	3,507
15		1,997	2,403	2,809	3,217	3,625	4,034
16		2,276	2,739	3,202	3,667	4,132	4,598
17		2,574	3,097	3,621	4,147	4,673	5,200
18			3,478	4,067	4,656	5,247	5,839
19			3,881	4,538	5,196	5,856	6,516
20			4,307	5,036	5,766	6,498	7,231
21			4,755	5,560	6,366	7,174	7,983
22			5,225	6,110	6,996	7,884	8,773

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.19275\ (D^2Th)^{1.00974}$.
[4]$Y = 0.15519\ (D^2Th)^{1.01440}$.

Table 11.—Predicted green weight of wood and bark in saw-log stem to 8-inch d.i.b. or saw-log merchantable top for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)					
	50	60	70	80	90	100
	Pounds					
	WOOD AND BARK[3]					
11	600	728	856	986	1,117	1,248
12	721	874	1,029	1,185	1,342	1,500
13	854	1,036	1,219	1,404	1,590	1,777
14	999	1,211	1,426	1,642	1,859	2,078
15	1,156	1,401	1,649	1,899	2,151	2,405
16	1,325	1,606	1,890	2,177	2,466	2,756
17	1,506	1,826	2,149	2,475	2,803	3,133
18		2,060	2,425	2,792	3,163	3,535
19		2,310	2,718	3,130	3,545	3,963
20		2,574	3,030	3,489	3,951	4,417
21		2,854	3,359	3,868	4,381	4,897
22		3,149	3,706	4,268	4,833	5,403
	WOOD[4]					
11	517	628	740	854	968	1,083
12	623	756	891	1,027	1,165	1,303
13	739	897	1,057	1,218	1,381	1,545
14	865	1,050	1,238	1,427	1,617	1,809
15	1,002	1,216	1,433	1,652	1,873	2,096
16	1,149	1,396	1,645	1,896	2,149	2,404
17	1,308	1,588	1,871	2,157	2,445	2,736
18		1,794	2,114	2,436	2,762	3,090
19		2,012	2,371	2,734	3,099	3,467
20		2,245	2,645	3,049	3,457	3,867
21		2,491	2,935	3,383	3,835	4,291
22		2,750	3,241	3,736	4,235	4,738

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.06044\ (D^2Th)^{1.05689}$.
[4]$Y = 0.04863\ (D^2Th)^{1.06485}$.

Table 12.—Predicted green weight of wood and bark in stem to 4-inch d.i.b. top for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)						
	40	50	60	70	80	90	100
	Pounds						
	WOOD AND BARK[3]						
5	132	167	202	238	274		
6	194	245	297	350	402		
7	268	339	411	484	557		
8	355	450	545	641	738	836	
9	456	576	699	822	946	1,071	
10	569	720	872	1,026	1,182	1,338	1,495
11	696	880	1,067	1,255	1,444	1,635	1,828
12	836	1,057	1,281	1,507	1,735	1,965	2,195
13	989	1,252	1,517	1,785	2,054	2,326	2,599
14		1,463	1,773	2,086	2,402	2,719	3,039
15		1,692	2,051	2,413	2,778	3,145	3,514
16		1,939	2,350	2,765	3,183	3,603	4,027
17		2,204	2,670	3,142	3,616	4,095	4,576
18			3,012	3,544	4,080	4,619	5,162
19			3,376	3,972	4,572	5,177	5,785
20			3,762	4,425	5,094	5,768	6,445
21			4,169	4,905	5,646	6,393	7,144
22			4,599	5,410	6,228	7,052	7,880
	WOOD[4]						
5	112	142	172	203	234		
6	165	209	254	299	344		
7	229	290	352	415	478		
8	304	385	467	550	634	719	
9	390	495	600	707	814	923	
10	488	619	751	884	1,019	1,154	1,291
11	598	757	919	1,082	1,247	1,413	1,580
12	719	911	1,105	1,302	1,500	1,700	1,901
13	852	1,080	1,310	1,543	1,778	2,015	2,253
14		1,263	1,533	1,806	2,081	2,358	2,637
15		1,463	1,775	2,091	2,409	2,730	3,053
16		1,678	2,036	2,398	2,763	3,131	3,501
17		1,908	2,315	2,727	3,142	3,560	3,982
18			2,614	3,079	3,547	4,020	4,495
19			2,932	3,453	3,979	4,509	5,042
20			3,269	3,850	4,437	5,027	5,622
21			3,626	4,270	4,921	5,576	6,236
22			4,002	4,714	5,431	6,155	6,883

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.09079 (D^2Th)^{1.05414}$.
[4]$Y = 0.07333 (D^2Th)^{1.06140}$.

Table 13.—Predicted green weight of wood and bark in crown for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)						
	40	50	60	70	80	90	100
	Pounds						
	WOOD AND BARK[3]						
5	70	86	102	118	134		
6	98	121	144	166	189		
7	131	162	192	222	252		
8	169	208	247	285	323	361	
9	211	259	308	356	403	450	
10	256	316	375	433	491	548	605
11	307	378	448	518	587	656	724
12	361	445	528	610	691	772	852
13	419	517	613	709	803	897	990
14		594	705	814	923	1,030	1,137
15		676	802	927	1,050	1,173	1,294
16		763	905	1,046	1,185	1,323	1,461
17		855	1,014	1,172	1,328	1,483	1,637
18			1,129	1,304	1,478	1,650	1,822
19			1,249	1,443	1,636	1,826	2,016
20			1,375	1,589	1,801	2,011	2,219
21			1,507	1,741	1,973	2,203	2,432
22			1,644	1,900	2,153	2,404	2,654
	WOOD[4]						
5	56	69	81	94	106		
6	78	96	114	132	149		
7	104	128	152	175	198		
8	134	164	195	225	254	284	
9	166	205	242	280	317	353	
10	202	249	295	340	385	430	474
11	241	297	352	406	460	513	566
12	284	349	414	477	540	603	665
13	329	405	480	554	627	699	771
14		465	551	636	719	803	885
15		529	626	722	818	912	1,006
16		596	706	815	922	1,029	1,135
17		667	790	912	1,032	1,151	1,270
18			879	1,014	1,148	1,280	1,412
19			971	1,121	1,269	1,416	1,561
20			1,068	1,233	1,396	1,557	1,717
21			1,170	1,350	1,528	1,705	1,880
22			1,275	1,472	1,666	1,859	2,050

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.10793\ (D^2Th)^{0.93721}$.
[4]$Y = 0.09108\ (D^2Th)^{0.92903}$.

Table 14.—Predicted volume of above-stump total-tree wood and bark for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD AND BARK[3]						
5	3.2	4.0	4.8	5.6	6.4		
6	4.6	5.8	6.9	8.1	9.2		
7	6.3	7.8	9.4	11.0	12.6		
8	8.2	10.3	12.3	14.4	16.4	18.5	
9	10.4	13.0	15.6	18.2	20.8	23.4	
10	12.8	16.0	19.3	22.5	25.7	28.9	32.2
11	15.5	19.4	23.3	27.2	31.1	35.0	39.0
12	18.5	23.1	27.8	32.4	37.1	41.7	46.4
13	21.7	27.2	32.6	38.1	43.5	49.0	54.5
14		31.5	37.9	44.2	50.5	56.9	63.2
15		36.2	43.5	50.8	58.0	65.3	72.6
16		41.2	49.5	57.8	66.1	74.4	82.6
17		46.6	55.9	65.3	74.6	84.0	93.3
18			62.7	73.2	83.7	94.2	104.7
19			69.9	81.6	93.3	105.0	116.7
20			77.5	90.4	103.4	116.4	129.3
21			85.4	99.7	114.0	128.3	142.7
22			93.8	109.5	125.2	140.9	156.6
	WOOD[4]						
5	2.6	3.2	3.9	4.5	5.2		
6	3.7	4.7	5.6	6.6	7.5		
7	5.1	6.4	7.7	9.0	10.3		
8	6.7	8.4	10.1	11.8	13.5	15.2	
9	8.5	10.7	12.8	15.0	17.2	19.3	
10	10.5	13.2	15.9	18.6	21.3	24.0	26.7
11	12.8	16.0	19.3	22.5	25.8	29.1	32.4
12	15.2	19.1	23.0	26.9	30.8	34.7	38.6
13	17.9	22.5	27.0	31.6	36.2	40.8	45.4
14		26.1	31.4	36.8	42.1	47.4	52.8
15		30.1	36.2	42.3	48.4	54.6	60.7
16		34.3	41.2	48.2	55.2	62.2	69.2
17		38.7	46.6	54.5	62.4	70.3	78.3
18			52.3	61.2	70.1	79.0	87.9
19			58.4	68.3	78.2	88.1	98.1
20			64.8	75.8	86.8	97.8	108.9
21			71.6	83.7	95.8	108.0	120.2
22			78.7	92.0	105.3	118.7	132.1

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.00311 (D^2Th)^{1.00368}$.
[4]$Y = 0.00233 (D^2Th)^{1.01465}$.

Table 15.—Predicted volume of wood and bark in saw-log stem to 8-inch d.i.b. or saw-log merchantable top for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)					
	50	60	70	80	90	100
	Cubic feet					
	WOOD AND BARK[3]					
11	8.9	10.8	12.7	14.7	16.7	18.7
12	10.7	13.0	15.4	17.7	20.1	22.6
13	12.7	15.5	18.2	21.1	23.9	26.8
14	14.9	18.1	21.4	24.7	28.1	31.4
15	17.3	21.0	24.8	28.7	32.6	36.5
16	19.9	24.2	28.6	33.0	37.4	41.9
17	22.6	27.6	32.5	37.6	42.7	47.8
18		31.2	36.8	42.5	48.3	54.1
19		35.0	41.4	47.8	54.2	60.8
20		39.1	46.2	53.4	60.6	67.9
21		43.5	51.3	59.3	67.3	75.4
22		48.1	56.7	65.5	74.4	83.4
	WOOD[4]					
11	7.5	9.1	10.8	12.5	14.2	15.9
12	9.0	11.0	13.0	15.1	17.2	19.3
13	10.8	13.1	15.5	18.0	20.5	23.0
14	12.6	15.4	18.3	21.2	24.1	27.0
15	14.7	18.0	21.3	24.6	28.0	31.4
16	16.9	20.7	24.5	28.3	32.2	36.2
17	19.3	23.6	28.0	32.4	36.8	41.3
18		26.8	31.7	36.7	41.7	46.8
19		30.1	35.7	41.3	47.0	52.7
20		33.7	39.9	46.2	52.6	59.0
21		37.5	44.4	51.4	58.5	65.6
22		41.5	49.2	56.9	64.8	72.7

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.00074\ (D^2Th)^{1.07831}$.
[4]$Y = 0.00054\ (D^2Th)^{1.09480}$.

Table 16.—Predicted volume of wood and bark in stem to 4-inch d.i.b. top for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD AND BARK[3]						
5	2.0	2.5	3.1	3.6	4.1		
6	2.9	3.7	4.5	5.3	6.1		
7	4.0	5.1	6.2	7.3	8.4		
8	5.4	6.8	8.2	9.7	11.1	12.6	
9	6.9	8.7	10.5	12.4	14.3	16.1	
10	8.6	10.9	13.2	15.5	17.8	20.2	22.5
11	10.5	13.3	16.1	18.9	21.8	24.6	27.5
12	12.6	15.9	19.3	22.7	26.2	29.6	33.1
13	14.9	18.9	22.9	26.9	31.0	35.1	39.2
14		22.1	26.7	31.4	36.2	41.0	45.8
15		25.5	30.9	36.4	41.9	47.4	53.0
16		29.2	35.4	41.7	48.0	54.3	60.7
17		33.2	40.2	47.3	54.5	61.7	69.0
18			45.4	53.4	61.5	69.6	77.8
19			50.9	59.9	68.9	78.0	87.2
20			56.7	66.7	76.8	86.9	97.1
21			62.8	73.9	85.1	96.3	107.6
22			69.3	81.5	93.9	106.3	118.7
	WOOD[4]						
5	1.7	2.1	2.6	3.0	3.5		
6	2.4	3.1	3.8	4.4	5.1		
7	3.4	4.3	5.2	6.2	7.1		
8	4.5	5.7	7.0	8.2	9.5	10.7	
9	5.8	7.4	9.0	10.6	12.2	13.8	
10	7.3	9.2	11.2	13.2	15.2	17.3	19.3
11	8.9	11.3	13.7	16.2	18.7	21.2	23.7
12	10.7	13.6	16.5	19.5	22.5	25.5	28.5
13	12.7	16.2	19.6	23.1	26.7	30.3	33.9
14		18.9	23.0	27.1	31.3	35.4	39.7
15		21.9	26.6	31.4	36.2	41.1	46.0
16		25.2	30.6	36.0	41.6	47.1	52.7
17		28.6	34.8	41.0	47.3	53.7	60.0
18			39.3	46.4	53.5	60.6	67.8
19			44.1	52.0	60.0	68.0	76.1
20			49.2	58.0	66.9	75.9	84.9
21			54.6	64.4	74.3	84.2	94.3
22			60.3	71.1	82.0	93.0	104.1

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.00119\,(D^2Th)^{1.05828}$.
[4]$Y = 0.00104\,(D^2Th)^{1.06736}$.

Table 17.—Predicted volume of wood and bark in crown for scarlet oak trees[1]

D.b.h. (inches)	Total-tree height[2] (feet)						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD AND BARK[3]						
5	1.1	1.4	1.6	1.9	2.1		
6	1.6	1.9	2.3	2.6	3.0		
7	2.1	2.6	3.1	3.5	4.0		
8	2.7	3.3	3.9	4.5	5.1	5.7	
9	3.3	4.1	4.8	5.6	6.3	7.0	
10	4.1	5.0	5.9	6.8	7.7	8.6	9.4
11	4.8	5.9	7.0	8.1	9.1	10.2	11.2
12	5.7	7.0	8.2	9.5	10.7	12.0	13.2
13	6.6	8.1	9.5	11.0	12.4	13.9	15.3
14		9.3	10.9	12.6	14.3	15.9	17.5
15		10.5	12.4	14.3	16.2	18.1	19.9
16		11.8	14.0	16.1	18.3	20.3	22.4
17		13.2	15.7	18.0	20.4	22.8	25.1
18			17.4	20.1	22.7	25.3	27.9
19			19.2	22.2	25.1	27.9	30.8
20			21.1	24.4	27.5	30.7	33.8
21			23.1	26.6	30.1	33.6	37.0
22			25.2	29.0	32.8	36.6	40.3
	WOOD[4]						
5	0.9	1.1	1.3	1.5	1.6		
6	1.2	1.5	1.8	2.0	2.3		
7	1.6	2.0	2.3	2.7	3.1		
8	2.1	2.5	3.0	3.4	3.9	4.3	
9	2.6	3.1	3.7	4.3	4.8	5.4	
10	3.1	3.8	4.5	5.2	5.9	6.5	7.2
11	3.7	4.5	5.4	6.2	7.0	7.8	8.6
12	4.3	5.3	6.3	7.3	8.2	9.1	10.1
13	5.0	6.2	7.3	8.4	9.5	10.6	11.7
14		7.1	8.4	9.6	10.9	12.1	13.4
15		8.0	9.5	10.9	12.4	13.8	15.2
16		9.0	10.7	12.3	13.9	15.5	17.1
17		10.1	12.0	13.8	15.6	17.3	19.1
18			13.3	15.3	17.3	19.3	21.2
19			14.7	16.9	19.1	21.3	23.4
20			16.1	18.6	21.0	23.4	25.8
21			17.6	20.3	23.0	25.6	28.2
22			19.2	22.1	25.0	27.9	30.7

[1]Blocked-in area indicates range of data.
[2]Includes 1-foot stump allowance.
[3]$Y = 0.00194 (D^2Th)^{0.92165}$.
[4]$Y = 0.00153 (D^2Th)^{0.91833}$.

U.S. Government Printing Office: 1981- 735-056/4022 Region No. 3-11

Clark, Alexander, III, Douglas R. Phillips, and Harry C. Hitchcock III.
1980. Predicted weights and volumes of scarlet oak trees on the Tennessee Cumberland Plateau. USDA For. Serv., Res. Pap. SE-214, 23 p. Southeast. For. Exp. Stn., Asheville, N.C.

Equations are presented for predicting green and dry weight and green volume of the total tree above stump and its components using d.b.h. and total height, d.b.h. and height to a 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Tables developed from equations show weight and volume of the total tree and its components by d.b.h. and total height class.

KEYWORDS: *Quercus coccinea* Muenchh., biomass, component proportions, equations, specific gravity, moisture content, weight per cubic foot.

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SE-215

A TECHNIQUE FOR INVENTORYING VOLUMES AND WEIGHTS OF WINDROWED FOREST RESIDUES

by W. Henry McNab

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All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor.

CONVERSION TABLE

Multiply	*By*	*To obtain*
Inches	2.540	centimeters
Feet	.3048	meters
Pounds	.4536	kilograms
Cubic feet	.02832	cubic meters
Pounds per cubic foot	16.02	kilograms per cubic meter

September 1980
Southeastern Forest Experiment Station
Asheville, North Carolina

A Technique for Inventorying Volumes and Weights of Windrowed Forest Residues[1]

by
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ABSTRACT.—Dimensions and cross-sectional areas of 28 windrows at three sites in Georgia were sampled along line transects. The number and diameter of tree stems and limbs intersected by the transects were recorded. Regression analysis revealed that 94 percent of the variation in the proportion of wood was explained by seven of the measured variables. However, sufficiently accurate ($R^2 = 0.88$) estimates of the proportion of wood could be obtained using only two easily estimated variables, (1) maximum windrow height, and (2) average diameter of woody material at least 3 inches in diameter.

Keywords: Biomass, logging residues, prediction equations, Georgia Piedmont, windrow, debris, site preparation, fuelwood.

In the South, recently logged sites are often prepared for pine planting by shearing off unmerchantable trees at groundline and windrowing them along with the logging slash (fig. 1). The windrows often contain considerable amounts of wood that might well be used as fuel. Utilization of this wood depends in part on having a reliable method for estimating the weight of wood in a windrow. A literature search revealed that no practical method has been reported. This Paper describes a technique whose promise was demonstrated in a formal study.

A windrow typically contains pieces of wood ranging from considerably less than 1 inch to 16 or more inches in diameter. Lengths are equally variable. It is easy enough to observe the characteristics of the pieces that are on the surface, but very difficult to tell what lies beneath. The purpose of my study was to evaluate the relationships between windrow characteristics and their biomass contents—to determine whether certain features are good indicators of the volume of wood present.

Figure 1.—In the South, unmerchantable trees and logging residues are often windrowed to prepare sites for pine planting. This wood is either burned or left to decay, but it might be utilized.

[1]This study was conducted in cooperation with the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System.

FIELD METHODS AND ANALYSIS

The study was conducted on three recently logged areas on the Oconee National Forest, which is in the lower Piedmont of Georgia. Merchantable loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pines were harvested by tree-length logging to a 4-inch top. An unmerchantable, and uninventoried, residual stand of various-sized hardwoods remained on the site following harvest. It consisted of oaks (*Quercus* spp.), maples (*Acer* spp.), and other minor upland species. In the fall of the year of logging, the areas were prepared for reforestation by shearing the residual trees at groundline with a sharp blade mounted on a crawler tractor.

Windrows were formed using a crawler tractor equipped with a brush rake attachment to push the sheared trees and debris into windrows which extended along the contour. Individual windrows were spaced about 200 feet apart in generally parallel rows. The topography of the study sites was gently rolling, with slopes averaging less than 10 percent. Surface soils were primarily eroded sandy clays, with clay subsoils. The same contractor performed the site preparation work at all three sites.

The following spring, the dimensions of windrow cross sections perpendicular to the long axis were measured at sample points spaced about 250 feet apart. Since many small pieces were sticking out, we located boundaries at pieces 3 inches or larger in diameter. Depth to the soil surface was measured, and metal rods were inserted vertically through the residues to mark undisturbed dimensions. Rods were inserted wherever there was an obvious change in the profile (fig. 2).

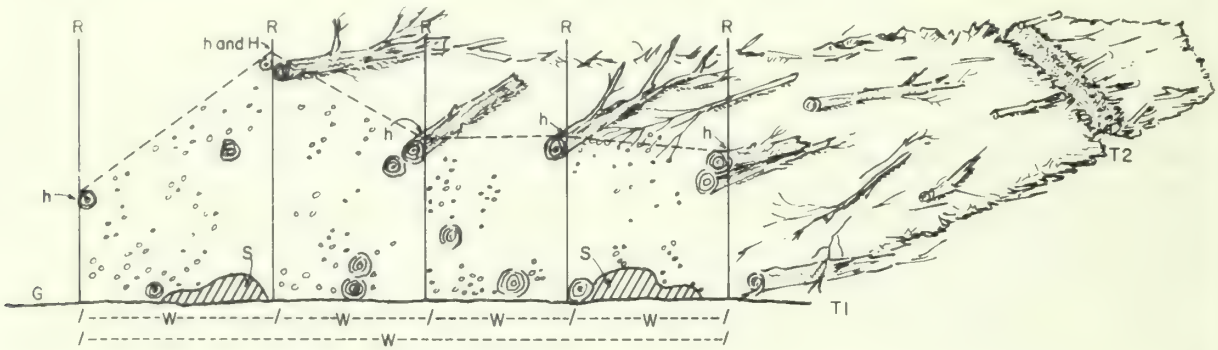

Figure 2.—Sample transect lines (T1, T2) through typical windrow. Cross-sectional area is delineated by metal rods (R) at various distances from the edge (w), where windrow surface (h) changes. Total windrow width (W) and maximum height (H) were determined. Cross-sectional areas of small (¼–1 inch), medium (1–3 inch), and large (≥ 3-inch) diameter residues and area of included soil (S) above assumed ground line (G) were measured.

Using a chain saw, we then cut a narrow path through the windrow at each sample point. In many instances, the windrow settled below the profile marked by the rods. The following independent variables were measured at each sample point:

1. Total windrow width (ft).
2. Undisturbed height (ft) of debris at each metal rod.
3. Depth (ft) of soil included in the windrow.
4. Total number of intersected pieces in small (0.25–1 in) diameter class.
5. Total number of intersected pieces in medium (1–3 in) diameter class.
6. Total number and diameter of intersected pieces in large (≥ 3 in) diameter class.
7. Windrow cross-sectional profile area (ft^2).
8. Woody residues cross-sectional area (ft^2).

The purpose of the estimates, measurements, and subsequent analysis was twofold. First, we wanted to know whether cross-sectional areas could be adequately estimated without digging into the pile. Next, we wanted to know whether a wood ratio—proportion of the area in solid wood—could be similarly estimated. From the cross-sectional area and the wood ratio, an area of solid wood represented by the cross section can be computed. And if the area of wood at each change in pile geometry can be estimated, it is a simple matter to compute wood volume in the pile as a whole. All one has to do is measure the length of the pile.

The data set for analysis consisted of observations from 54 windrow cross sections. Using SAS[2] multiple-regression programs, the eight measured independent variables, and various transformations and combinations of the variables, were analyzed to develop a prediction equation for the dependent variable of wood ratio. Only variables that significantly reduced residual mean square error at the 0.05 level were included, and the equation with the smallest residual mean square error was considered best.

RESULTS AND DISCUSSION

Windrow Dimensions

Even though a typical windrow appears to be disorganized, with logs and treetops extending out of the surface, the dimensions were easily defined. Total width was usually well defined by pieces greater than 3 inches in diameter at the edges of the windrow. Height was more difficult to measure than width, but could consistently be determined by visualizing an imaginary solid windrow surface, as if a sheet were draped over residues at least 3 inches in diameter. Field data characterizing the physical size of the windrows are summarized in table 1.

and might account for the narrower windrows. Windrow length, which varied according to land form and access requirements, usually ranged from 100 to 500 feet.

The windrow shapes, or profile outlines, varied considerably. Many were skewed, with a high point on one side, while others were relatively flat piles with no defined peaks. The ranges of profile sizes and shapes are shown in figure 3.

Windrow Contents

The mean number, size, and cross-sectional area of woody residues per sample line at each location are shown in table 2. The principal variable in table 2, however, is the computed wood ratio or proportion of the profile area occupied by solid wood. The mean values of wood ratio at each location were extremely close, especially considering the variations in windrow profile area and in number and size of pieces. Variation would probably have been greater if different contractors had prepared the three areas.

A wide range in values of wood ratio—0.01 to 0.34—was sampled, however. Ratios were most uniform at location I and ranged about equally in extremes at the other two areas. Sample points with very low wood ratios usually contained only

Table 1.—Means and ranges of windrow dimensions and cross-sectional areas measured on three pine-hardwood clearcut sites on the Oconee National Forest

Location	Windrows measured	Transects sampled	Windrow height		Windrow width		Cross-sectional areas[1]
			Average	Range	Average	Range	
	No.		*ft*				*ft²*
I	6	6	3.4	2.0–6.0	6.7	5.0–11.0	24.4
II	17	33	3.9	1.8–8.1	10.6	3.4–19.8	29.8
III	5	15	3.3	1.8–5.3	9.3	2.5–17.1	23.4
All locations	28	54	3.7	1.8–8.1	9.8	2.5–19.8	27.4

[1]Average of all transects sampled at each location.

Windrow heights were similar at the three sample locations. Mean windrow width at location I was about 3 feet less than at the other two locations. A greater proportion of pine, which is more easily compacted, was present at location I

a few small-diameter pieces of wood suspended above the ground level by other residues on either side of the transect line. Conversely, high wood ratios generally resulted from compact piles of large-diameter pieces. However, there were numerous exceptions to this generalization.

[2]S.A.S. 1979. SAS user's guide. 494 p. J. T. Helwig and K. A. Council, editors. SAS Institute, Inc., Raleigh, N.C.

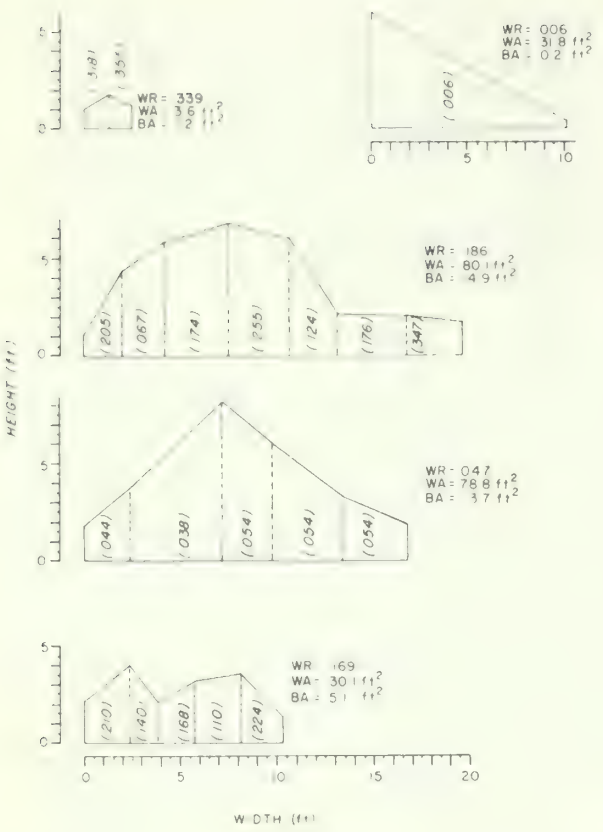

Figure 3.—Characteristics of selected cross sections of sampled windrows, including wood ratio (WR), windrow cross-sectional area (WA), and biomass cross-sectional area (BA).

residues especially suitable as fuelwood because grit is not present to dull chipper cutting knives and interfere with boiler operation.

Predicting Wood Ratio

An analysis of variance revealed no significant differences in estimated wood ratios among the three locations. The data, therefore, were pooled to form a single data base of 54 observations for regression analysis. The equation that fits the field data best, with an R^2 of 0.948, is:

$$\text{Wood ratio} = (0.808 - 0.00972X_1 - 0.0000122X_2 + 0.340X_3 - 3.84X_4 + 5.53X_5 + 0.00345X_6 + 0.000412X_7)^2 \quad (1)$$

where:

X_1 = Windrow width (ft),
X_2 = Windrow profile area $(ft^2)^2$,
X_3 = Windrow maximum height $(ft)^{-1}$,
X_4 = Mean diameter of pieces ≥ 3 inches $(in)^{-1}$,
X_5 = Mean diameter of pieces ≥ 3 inches $(in)^{-2}$,
X_6 = Pieces of intersected residue ≥ 3 inches diameter (No.),
X_7 = Total of all intersected pieces of residue (No.).

Table 2.—Mean quantity, cross-sectional area, size, and ratio of woody residues measured at sample points in windrows at three locations on the Oconee National Forest

Location	Quantity, by diameter class (inches)			Cross-sectional area, by diameter class (inches)				Average diameter residues ≥ 3 inches	Wood ratio		
	¼–1	1–3	3+	¼–1	1–3	3+	All		Mean	Min.	Max.
	No.			ft^2				in			
I	45	42	12	0.10	0.90	1.81	2.81	5.4	0.17	0.13	0.19
II	65	34	19	.14	.73	3.01	3.88	5.2	.15	.01	.31
III	93	53	15	.20	1.15	2.47	3.82	5.7	.19	.06	.34
Mean	71	40	17	.15	.87	2.73	3.75	5.4	.16	—	—

Appreciable amounts of soil were observed in the windrows at only two places on the three study sites. Normally, some soil becomes mixed with the residues and is included in the windrows. On these areas, shearing was done with a sharp blade to avoid uprooting stumps, and raking was intentionally light to leave brush to reduce erosion. The lack of soil makes these windrowed

The standard error of estimate of equation (1) is 0.0246, or about 2.5 percent.

Operational Model

Although equation (1) accounts for about 95 percent of the variation in wood ratio, it is impractical to measure its input variables. Therefore, the

data were reexamined to find variables that can be evaluated and measured easily. These variables include windrow height and width and the estimated diameter of large residues (greater than 3 inches diameter) visible on the surface of the cross section. I hypothesized that an estimate of the number of residue pieces should not be essential, because windrow height and width could be considered as indicators of the size and number of tree stems and large branches.

These variables, and various transformations, were analyzed by regression. The equation which best fits these data is:

$$\text{Wood ratio} = (0.635 + 0.251/H - 1.625/D)^2 \quad (2)$$

where H is maximum windrow height and D is mean diameter of residues larger than 3 inches. Equation (2) has an R^2 of 0.88 and a standard error of estimate for wood ratio of 0.036, only 1.1 percent greater than for equation (1), which required seven variables.

Using my basic field data, I determined the relationship between the mean diameter, in 2-inch classes, of large residues visible on the windrow surface at the sample point, and all large residues in the windrow. A regression analysis of the 54 data points revealed that the estimated and actual diameters were linearly related and highly correlated, with $R^2 = 0.79$ (fig. 4). The standard error of estimate was 0.6 inch.

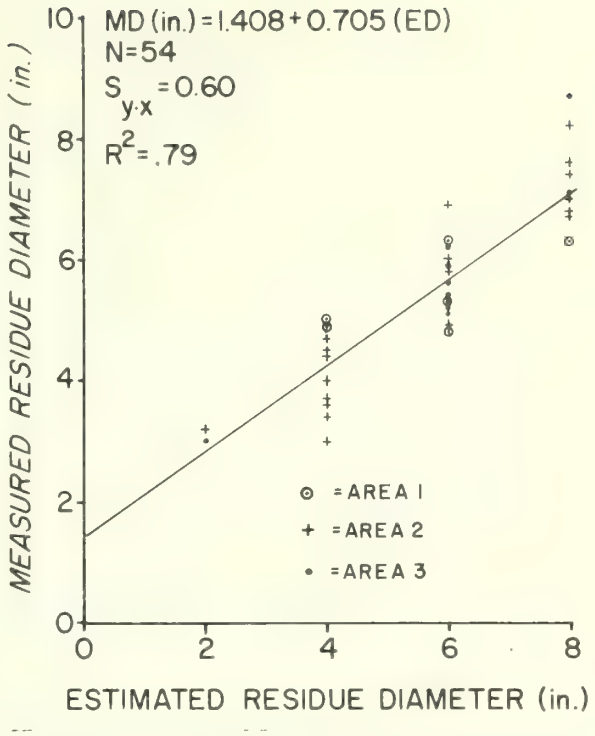

Figure 4.—The estimated diameter (ED) of residue pieces greater than 3 inches in diameter on the windrow surface at the 54 sample points was directly related to the average measured diameter (MD) of all large residues measured in the windrow.

Test of Equations

The equations for predicting windrow wood ratio were tested on data from 10 additional sampling points at the three locations. Data from these 10 sampling points are summarized in table 3.

Observed and predicted wood ratios are plotted in figures 5 and 6. Predicted values are uniformly distributed about the 45° line of perfect correlation. Equation (1) predicted an average wood ratio 0.0045 greater than the observed value. The mean absolute deviation of predicted minus observed value, expressed as a percent of observed, was 11.5 percent. For equation (2) the predicted ratio was 0.0040 less than observed, and the mean absolute deviation was 17.4 percent.

In addition to wood ratio, two variables are required to calculate volume: (1) average

Table 3.—Characteristics of windrows and woody residues measured at three sites on the Oconee National Forest for testing the accuracy of equations for estimating wood ratio

Location	Transects sampled	Mean windrow			Average diameter residues ≥ 3 inches	Wood ratio		
		Width	Height	Cross-sectional area		Mean	Minimum	Maximum
	No.	*ft*	*ft*	*ft²*	in			
I	1	8.0	2.1	14.3	4.8	0.142	—	—
II	3	9.1	3.6	24.1	5.1	.150	0.028	0.267
III	6	8.7	3.2	22.8	5.9	.215	.162	.294

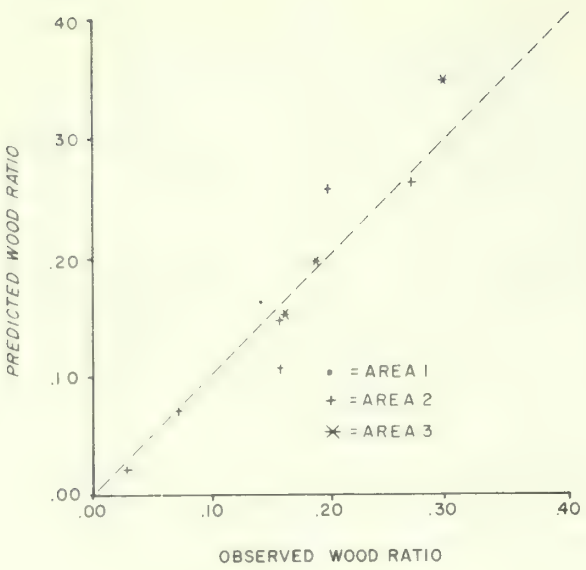

Figure 5.—Wood ratio predicted with equation (1) and observed for 10 sample transects. The 45° line represents perfect prediction.

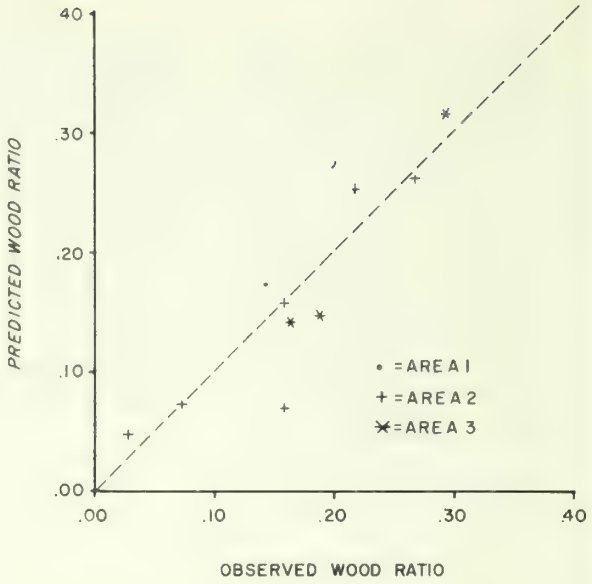

Figure 6.—Wood ratio predicted with equation (2) and observed for 10 sample transects. The 45° line represents perfect prediction.

cross-sectional area of the windrow, and (2) total length of windrows on the tract. Windrow cross-sectional area was estimated using maximum height and the horizontal distance from the near edge to this point. This method usually underestimated profile areas because of irregularities in windrow geometry. The underestimate was rather consistent, however. A prediction equation based on 54 observations was developed to determine the relationship between the estimated and observed windrow cross-sectional areas:

$$\text{Observed windrow area (ft}^2\text{)} = 3.39 + 1.19\,(\text{EPA}) \qquad (3)$$

where EPA is estimated profile area (ft^2) using the formula for the area of a rectangle (height × width). The relationship between actual and predicted EPA was close (fig. 7), with $R^2 = 0.96$.

Estimated Residue Weights

If one wishes to predict wood weight rather than volume, it is a simple matter to estimate the proportions of various tree species in piles and to convert volumes to weights. Appropriate factors for converting volume to weight for species or groups of species are contained in the *Wood Handbook*.[3] As shown in table 4, using data collected in this study, each unit volume of residues is then equal in weight to the calculated weighted value of wood density. For a general survey where species composition is not important, an average value of 35 lb/ft^3 could be applied with satisfactory results.

CONCLUSIONS

The high R^2 values and relatively small errors associated with equations (2) and (3) are highly encouraging. These equations cannot be used indiscriminately for predicting wood volume in windrows. The windrows for my study were all prepared by a single operator using a single piece of machinery. Considerably greater variation than that observed probably occurs.

Results of the study demonstrate, however, that the approach taken here can succeed. There appears to be no reason why a company, for example, cannot develop its own equations for predicting wood weights in the types of windrows it produces.

[3]U.S. Forest Products Laboratory. 1974. Wood handbook: Wood as an engineering material. U.S. Dep. Agric., Agric. Handb. 72, rev.

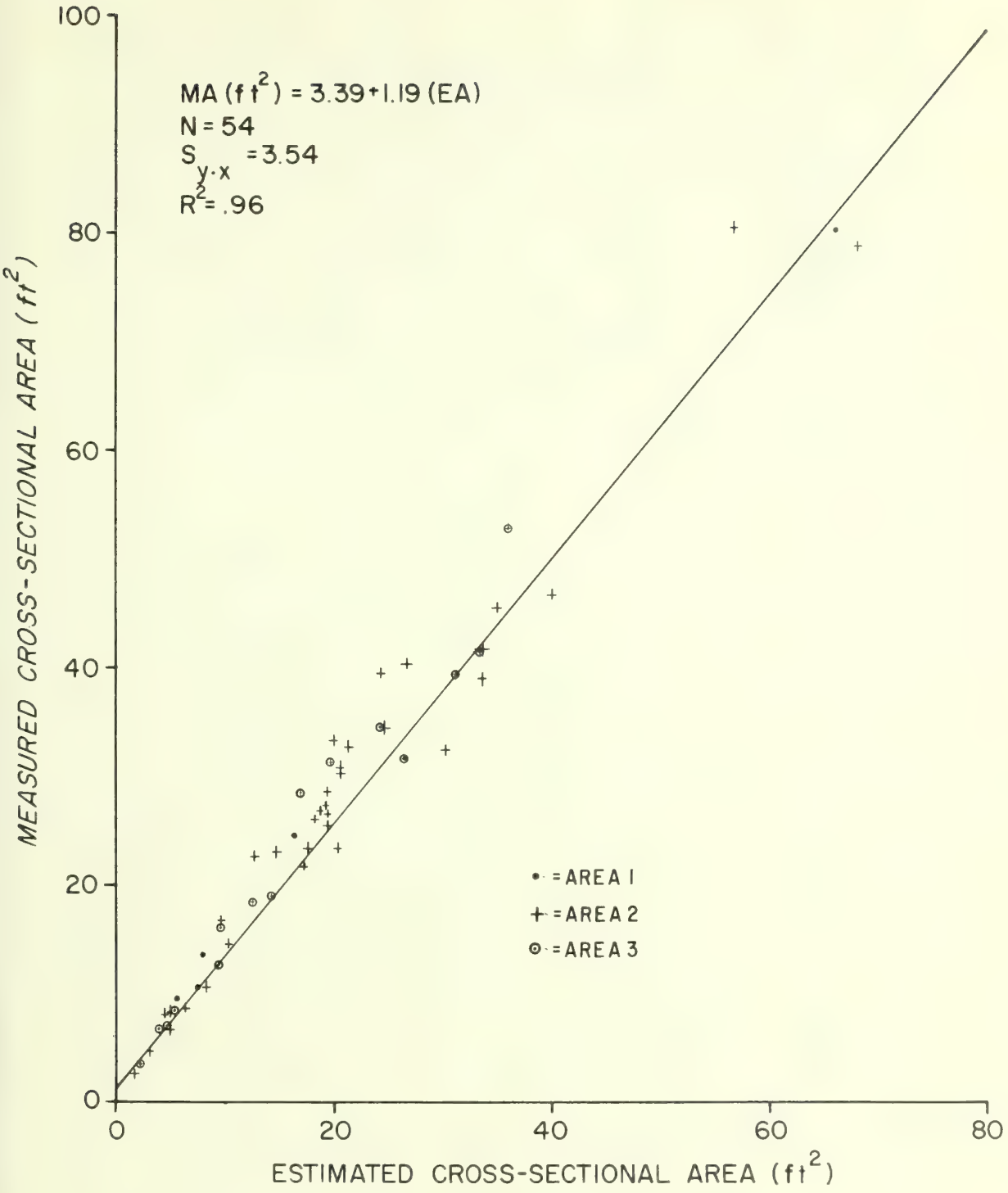

Figure 7.—Measured cross-sectional areas (MA) of windrows on three pine-hardwood clearcuts on the Oconee National Forest were closely related to estimated cross-sectional areas (EA) calculated from windrow height and width.

Table 4.—Conversion of residue volume to air-dry weight using weighted density for species groups inventoried

Species group	Proportion[1]	Air-dry density[2]	Weighted density
		..... *lb/ft*^{3}	
Loblolly pine	0.15	34.3	5.14
Soft hardwoods[3]	.25	32.4	8.10
Hard hardwoods[4]	.60	36.8	22.08
Total	1.00	—	35.32

[1]Residues 3-inch diameter
[2]12 percent moisture content.
[3]Sweetgum, yellow-poplar, maples.
[4]Oaks, hickories, elms.

McNab, W. Henry

1980. A technique for inventorying volumes and weights of windrowed forest residues. USDA For. Serv., Res. Pap. SE-215, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

The proportion of wood in windrow cross sections was estimated with reasonable accuracy ($R^2 = 0.88$) with a regression that includes two variables—maximum windrow height and average diameter of woody material at least 3 inches in diameter.

KEYWORDS: Biomass, logging residues, prediction equations, Georgia Piedmont, windrow, debris, site preparation, fuelwood.

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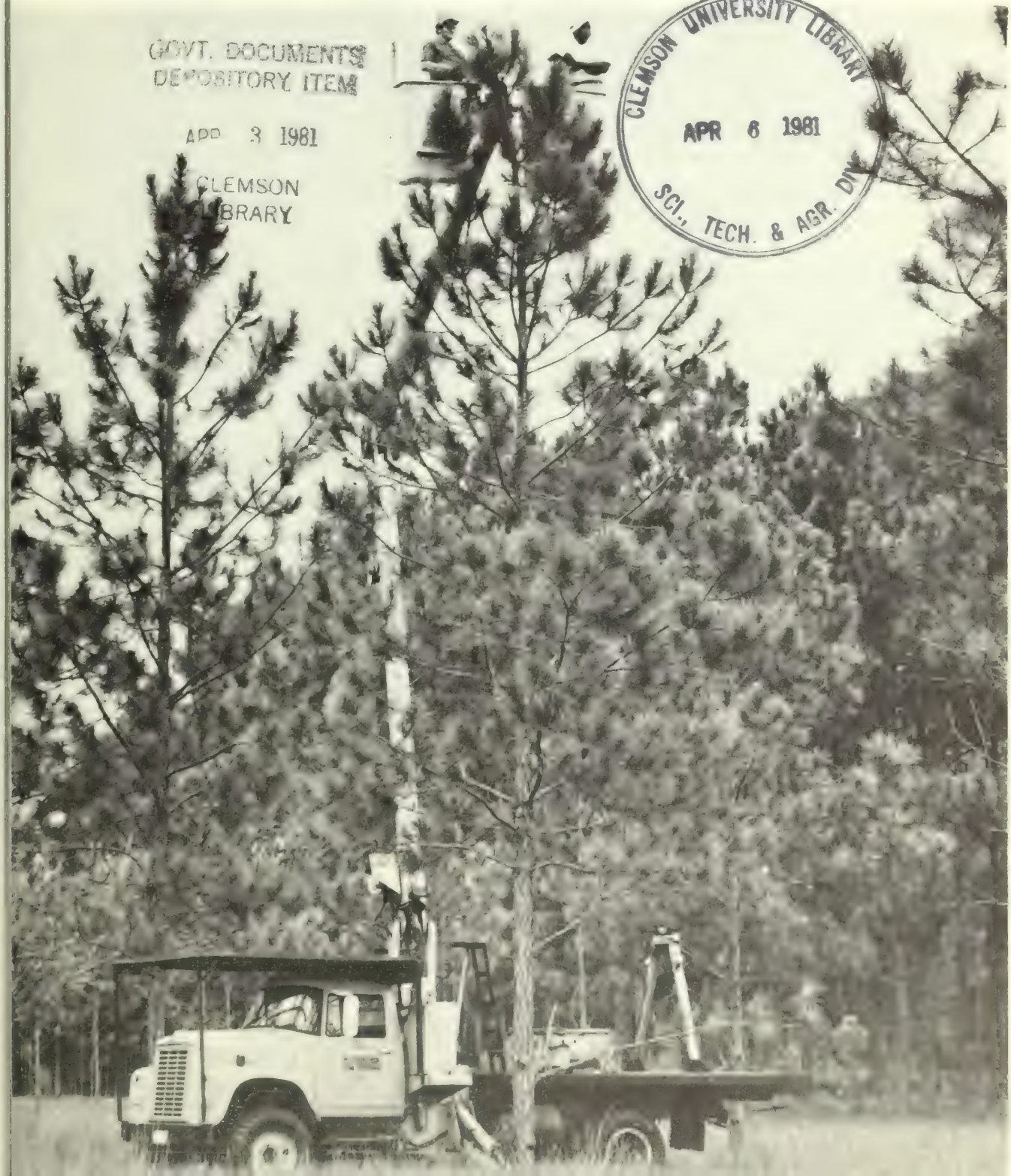

1980
Southeastern Forest Experiment Station
Asheville,North Carolina

Identification and Sequential Occurrence of Mortality Factors Affecting Seed Yields of Southern Pine Seed Orchards

by

Carl W. Fatzinger,[1] Gerard D. Hertel,[2] Edward P. Merkel,[1]
William D. Pepper,[3] and R. Scott Cameron[4]

ABSTRACT.—A survey of factors causing mortality of female strobili and reductions in seed quality of loblolly, longleaf, shortleaf, slash, and Virginia pines was conducted from 1973 to 1976. In general, more than half of the female strobili were lost between the flower and mature cone stages of development. Life table analyses indicated that the majority of the losses occurred during the spring of the first year of strobilus development. The primary mortality factors identified were coneworms, tip moths, loopers, the slash pine flower thrips, and strobilus abortion from unidentified causes. Differences in causes and rates of strobilus mortality between pine species, orchard locations, and years demonstrate the value of monitoring strobili in orchards to determine which management practices can be altered to obtain maximum seed yields. The majority of seed present in mature cones was viable. Empty seed and seed-bug damaged seed represented the two largest categories of nonviable seed.

Keywords: *Pinus taeda*, *P. elliottii*, *P. echinata*, *P. palustris*, *P. virginiana*, cone and seed insects, life tables, insect impact.

Forest managers are faced with the problem of producing greater volumes of wood on decreasing acreages of productive forest land. This dilemma has been created by the growing demands for alternate uses of forest lands and the increasing demand for forest products. Foresters are attempting to solve the problem by numerous means. One of the primary approaches is to produce more wood in shorter periods of time on less acreage through the use of genetically superior pines. The large quantities of seed needed for the nursery stock of these pines can only be produced economically in seed orchards.[5] More than 80 percent of these orchards are located in the Southern United States and most of them are now producing seed. Seed yields, however, have been low during certain years when losses of strobili[6] in excess of 75 percent have been recorded. Numerous mortality factors have been cited as causes for these heavy losses (tables 1 and 2). The percentages of loss attributed to the different mortality factors vary widely between years, species of pines, and locations. Some of this variability also stems from the different methods used to evaluate the losses.

During November 1972, representatives of the U.S. Forest Service, the Virginia Division of Forestry, the Texas Forest Service, Mississippi State University, and the Universities of Arkansas, Georgia, and Florida met at Olustee, Florida, and discussed problems related to the management of insects in southern pine seed orchards. The major problems delineated were the lack of sufficient information concerning mortality factors affecting seed production and the lack of a sampling method for detection surveys and control evaluations. An *ad hoc* Seed Orchard Insect Sampling Committee was formed to investigate these problems (Fatzinger and others 1975). In

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[5]A seed orchard is a plantation consisting of clones or seedlings from selected trees and cultured for early and abundant seed production (Bramlett and others 1977). A clone is a group of genetically identical plants (called ramets) derived asexually from a single individual (Snyder 1972).

[6]A "strobilus" is the male or female reproductive structure of pines. A "cone" is the female reproductive structure of pines, consisting of a central axis supporting bracts, each of which subtends a scale bearing naked seeds. The female strobili are classified as "flowers" before pollination, as "conelets" from the time of flower-scale closure after pollination until the initiation of rapid development of the cone a few months before maturity (Bramlett and others 1977). In this paper, female flowers, conelets, and cones are collectively referred to as "strobili" hereafter.

this paper we report the results of a survey conducted to determine the relative importance of mortality factors affecting seed production on the major species of pines grown in southern pine seed orchards. In the survey, the same procedures were used during the same period of time in all orchards sampled to reduce variability.

REVIEW OF THE LITERATURE

In the absence of insect control, losses of potential seed occur from the time the female strobili first become recognizable as buds until the cones mature about 20 months later. On the major species of southern pines, most losses of strobili occur during their first year of development. Over a 10-year period, only 33 to 60 percent of the cross-pollinated female flowers of loblolly, *Pinus taeda* L.; longleaf, *P. palustris* Mill.; shortleaf, *P. echinata* Mill.; and slash, *P. elliottii* Engelm. var. *elliottii*, pines survived to maturity in Arkansas, Florida, Georgia, Louisiana, and Mississippi, and 70 to 90 percent of these losses occurred during the first year of strobilus development (Snyder and Squillace 1966). Similar losses have been reported for these same species of pines during the first year of strobilus development by Wakeley (1931), Allen and Coyne (1955), Merkel (1961), Ebel (1964), Ciesla and others (1967), Morris and Schroeder (1967), DeBarr and Merkel (1971), Bramlett (1972a), McLemore (1973, 1977a, 1977b), DeBarr and Ebel (1974), Ebel and Yates (1974), DeBarr and Barber (1975), Fatzinger and others (1975), Overgaard and others (1975), Goyer and Nachod (1976), and Yates and Ebel (1978). Losses of strobili during their second year of development have been reported either as the losses occurring throughout the entire year, throughout part of the year, or at the time of cone harvest.

Strobilus abortion followed by abscission has been one of the major mortality factors. All factors causing abortion of strobili have not been identified but include an inadequate supply of pollen (Sarvas 1962), a possible imbalance of specific growth regulators (Bramlett 1972a), insect pests when not excluded by cages (Bramlett and Moyer 1973; DeBarr and others 1975b), and nymphal feeding by the seed bug *Leptoglossus corculus* (Say) (DeBarr and Ebel 1974; DeBarr and Kormanik 1975; McLemore 1977a).

The remainder of the losses are caused primarily by insects and occasionally by severe weather conditions. Collectively, insects have been reported to destroy from 68 to 97 percent of the longleaf pine conelets in Mississippi and Louisiana (Wakeley 1931; Allen and Coyne 1955), from 11 to 75 percent of the cones of loblolly pine (Knight 1952; Yearian and Warren 1964; Belcher and DeBarr 1975; Goyer and Nachod 1976), from 12 to 25 percent of the shortleaf pine strobili in Arkansas and Georgia (Yearian and Warren 1964; Coulson and Franklin 1968a, 1968b, 1970; Ebel and Yates 1974), and 35 percent of the slash pine strobili in Florida (Fatzinger and others 1975). The symptoms caused by insects which attack strobili of southern pines have been summarized in detail by Ebel and others (1975).

Pine coneworms, *Dioryctria* spp., frequently cause major losses of strobili of southern pines. Damage estimates range as high as 20 percent during the first year of development and 78 percent during the second year. The majority of reports, however, indicate a relatively low level of damage caused by coneworms during the first year (mode ca. 3 percent). Counts of infested cones collected at harvest were found to underestimate the total coneworm damage on slash pine during the second year of development by about 40 percent (DeBarr 1974a), and the mode of damage reports based on such counts is relatively high (ca. 17 percent). When the observations cited (table 1) are combined for estimates made during the second year of development and those made at cone harvest, the average mortality attributed to coneworms is about 16 percent but the mode is about 10 percent.

Pine coneborers, *Eucosma* spp., also destroy second-year strobili of loblolly, shortleaf, and Virginia pine, *P. virginiana* Mill. Although they have destroyed as many as 50 percent of these strobili, the average annual loss is about 16 percent. Pine tip moths, *Rhyacionia* spp., destroy strobili of loblolly and shortleaf pines and are considered to be a major mortality factor for first-year strobili of shortleaf pine.

Attacks by the slash pine flower thrips, *Gnophothrips fuscus* (Morgan), either kill the flowers of slash pine directly or cause a reduction of about one-third in seed yield from cones that survive attacks (DeBarr 1969). Thripslike damage has also been found on flowers of loblolly pine (Goyer and Nachod 1976), but the insect is considered to be of major importance only on slash pine.

Additional losses are attributed to unidentified or unknown insects directly feeding on strobili. Evidence of these attacks is often found

Table 1.—Summary of mortality factors reported to affect cone production of southern pines

Mortality factor	Tree species[a]	Percent mortality of strobili[b]							Reference[c]
		First-year flowers and conelets			Second-year conelets and cones		Harvested cones		
		$\bar{X}$	(Range)	[Mode]	$\bar{X}$	(Range)	$\bar{X}$	(Range) [Mode]	
Abortion	L	41	(10–73)		10	(3–26)		—	A, B, C, D, E,
	LL	26	(5–46)	[30]		—		—	F, G, H, I
	SL	19	(6–29)	[22]	12	(1–22)		—	
	S	25	(3–44)			—		—	
Total (L, LL, SL, S)		30	(3–73)	[23]		—		—	
Bird breakage	L, LL, SL, S	<1	(<1–<1)			—		—	F, G
Cone rust	S	4	(1– 8)			—		—	B, J
Coneworms	L	5	(<1–13)		28	(3–78)	18	(10–27)	B, C, D, E, G,
	LL	8	(4–13)		18	(3–46)		—	H, I, J, K, L, M
	SL	2	(<1– 7)		12	(<1–40)		—	
	S	12	(2–20)		19	(8–40)	21	(10–44) [17]	
Total (L, LL, SL, S)		7	(<1–20)	[3]	20	(<1–78)	20	(10–44) [17]	
Eucosma spp.	L		—		2	(1– 3)		—	D, E, I, M, N
	SL		—		14	(2–23)		—	
	V		—		44	(39–50)		—	
Total (L, SL, V)					16	(1–50)		—	
Hail	LL	6	—			—		—	G
	SL	20	—			—		—	
Loopers	L, SL	(d)	—			—		—	O
May beetles	L	7	(1–14)			—		—	F, G
	LL	1	—			—		—	
	SL	8	—			—		—	
Total (L, LL, SL)		6	(1–14)	[2]		—		—	
Midges	L	<1	—		5	(2– 9)	1	(<1– 1)	D, E, H, I, L, P
	SL	3	(1– 4)		10	(<1–25)		—	
	S	4	(1– 8)			—		—	
Total (L, SL, S)		3	(<1– 8)			—		—	
Missing	L	12	(6–18)		2	(1– 2)		—	D
	SL	33	(28–38)		18	—		—	
Sawflies	L	5	(2– 7)			—		—	D, I, Q
	SL	7	(4–10)			—		—	
Spring frost	SL	51	(39–63)			—		—	R
Thrips	S	24	(2–46)			—		—	B, J, S, T
	L	5[e]	—			—		—	
Tip moths	L	2	(<1– 6)			—		—	D, E, G, H, I,
	SL	22	(2–46)			—		—	M, S, U
Unknown insects	L	15	(2–35)		<1	(<1– 2)		—	D, E, F, G, I, J
	LL	47	—			—		—	
	SL	8	(2–25)			—		—	
	S	10	(9–12)			—		—	
Total (L, LL, SL, S)		14	(2–47)			—		—	

[a]Tree species are abbreviated as follows: L, loblolly pine; LL, longleaf pine; SL, shortleaf pine; S, slash pine; and V, Virginia pine.

[b]Percentages are rounded to the nearest whole number; the mode is given where the average did not reflect the majority of the observations cited.

[c]Letters listed refer to the following references: (A) Ciesla and others 1967, DeBarr and Ebel 1974, McLemore 1977a; (B) DeBarr and Barber 1975; (C) DeBarr and Merkel 1971, Ebel 1964; (D) Ebel 1974; (E) Ebel and Yates 1974; (F) McLemore 1973; (G) McLemore 1977b; (H) Yates and Ebel 1972; (I) Yates and Ebel 1978; (J) Merkel 1961; (K) Allen and Coyne 1955, Belcher and DeBarr 1975, Copony 1972, Coulson and Franklin 1970, DeBarr 1974a, Ebel 1965b, Knight 1952, Merkel 1959, 1969, 1970, Merkel and Yandle 1965, Merkel and others 1965, 1976, Sartor and Neel 1971; (L) Coulson and Franklin 1968a, b, Dohaney and Heikkenen 1968, Neel and Sartor 1969; (M) Morris and Schroeder 1967; (N) Ciesla and others 1968, Flavell and Maxwell 1976; (O) Ebel and DeBarr 1973; (P) Williams and Fatzinger 1977; (Q) Bramlett and Hutchinson 1965; (R) Bramlett 1972a; (S) Goyer and Nachod 1976; (T) DeBarr 1969, DeBarr and Matthews 1971, DeBarr and others 1972, Ebel 1961, 1965a, Merkel and Ebel 1961; and (U) Overgaard and others 1975.

[d]Observed damage.

[e]Reported as thripslike damage.

after the insects have left the strobili on which they fed. Thus, this category generally contains damage estimates resulting from attacks by new or unidentified insects, secondary insects, as well as known insects whose damage symptoms were obscure or not recognized. Other insects known to destroy strobili of southern pines include loopers, *Nepytia semiclusaria* (Walker); May beetles, *Phyllophaga micans* (Knoch); midges of the family Cecidomyiidae; and the sawflies, *Neodiprion pratti pratti* (Dyar) and *Xyela* spp. Although these insects are occasionally of major importance in pine seed orchards, the damage they cause is considered to be minor (range 0 to 6 percent).

Secondary insects reported to infest strobili that are dead or dying from other causes include the moths *Battaristis vitella* (Busch), *Moodna ostrinella* (Clemens), and *Holcocera* sp., and the beetles *Ernobius* sp. and *Pityophthorus* sp. (Ebel 1964; Yearian and Warren 1964; Franklin and Coulson 1968; Neel and Sartor 1969; Goyer and Nachod 1976).

Further losses are evident from examinations of seed extracted from harvested cones (table 2). The percentage of cones infested by pine seedworms, *Laspeyresia* spp., varies considerably among pine species (2 to 80 percent) with an average of about 35 percent for all species. Larval feeding destroys from 0 to 13 percent of the total seed in infested cones. Up to 63 percent of the total seed extracted from southern pine cones has been reported to be destroyed by the pine seed bugs, *L. corculus* and *Tetyra bipunctata* (H.-S.). These estimates of seed-bug damage, obtained by radiographing seed, are conservative because some of the seed classified as empty were probably destroyed by seed bugs (DeBarr 1974b).

Table 2.—Summary of factors reported to affect seed yield of southern pine cones

Factor	Tree species[a]	Cones infested[b]		Total seed damaged[b]		Reference[c]
		Percent	*(Range)*	*Percent*	*(Range)*	
Seedworms	L	19	(17–18)	2	(<1– 4)	A, B
	LL	44	(27–68)	13		
	SL	8	(>1–16)	2	(<1– 2)	
	S	40	(16–80)	4	(1–10)	
	V	4	(3– 5)	—	—	
Total (L, LL, SL, S, V)		32	(1–80)	—	—	
Seed bugs	L	—	—	9	(<1–28)	B, C, D
	SL	—	—	9	(<1–29)	
	S	—	—	11	(3–63)	
	V	—	—	4		
Total (L, SL, S, V)		—	—	10	(<1–63)	
Empty seed	L	—	—	22	(5–44)	B, C, E, F
	SL	—	—	39	(22–60)	
	S	—	—	19	(4–86)	
	V	—	—	31	(14–61)	
Total (L, SL, S, V)		—	—	23	(4–86)	
Aborted ovules	SL	—	—	69		D, E, G
	S	—	—	10	(8–14)	
	V	—	—	50	(29–69)	
Total (SL, S, V)		—	—	36	(8–69)	

[a]Tree species are abbreviated as follows: L, loblolly pine; LL, longleaf pine; SL, shortleaf pine; S, slash pine; and V, Virginia pine.

[b]Percentages are averages rounded to the nearest whole number.

[c]Letters listed refer to the following references: (A) Ciesla and Bell 1966, Ciesla and others 1967, DeBarr and Merkel 1971, Dohaney and Heikkenen 1968, Ebel 1971, Knight 1952; Merkel 1959, 1961, 1967a, 1967b, 1968, 1969, 1970; Merkel and Yandle 1965; (B) DeBarr and Barber 1975, Ebel and Yates 1974, Goyer and Nachod 1976; (C) Belcher 1974, DeBarr 1978, DeBarr and others 1975b, Ebel 1974, Merkel and others 1976; (D) DeBarr and others 1972, Merkel and DeBarr 1971; (E) Bramlett and Moyer 1973; (F) DeBarr 1974b; (G) Bramlett 1972b, 1974a.

Factors thought to cause empty seed include lethal gene combinations, lack of pollen, self-pollination, insects (particularly seed bugs), and environmental factors (Sarvas 1962; Franklin 1969a, 1969b; Bramlett and Popham 1971; Bramlett 1972b, 1974a; Bramlett and Moyer 1973; Bramlett and Pepper 1974; DeBarr and Ebel 1974; DeBarr and others 1975b; McLemore 1977a) and account for losses ranging from 4 to 86 percent of the extracted seed. During the first and second years of strobilus development, from 8 to 69 percent of the ovules are aborted before seedcoat formation primarily as a result of pollination failure and insect attacks (Sarvas 1962; Merkel and DeBarr 1971; DeBarr and others 1972; Bramlett and Moyer 1973; DeBarr and Ebel 1973; Bramlett 1974a, 1974b).

Recently Miller and Bramlett (1978) isolated two plant-pathogenic fungi, *Diplodia gossypina* Cke. and *Fusarium moniliforme* Sheld. var. *subglutinans* Wr. & Reink., that caused extensive damage to seed of slash pine. Both species of fungi were found capable of causing mortality of nearly mature cones when wounds were present as infection courts. *F. moniliforme* var. *subglutinans* was also demonstrated to be capable of causing abortion of female flowers and conelets.

METHODS

A survey was made of female strobili on five species of pine (loblolly, longleaf, shortleaf, slash, and Virginia) in six pine seed orchards located in six states (fig. 1, tables 3,4). The number of clones selected for sampling within each orchard depended on the amount of time available. Thus, the survey did not necessarily include sample strobili from all clones present in a given orchard. Insecticidal control measures were not applied to any of the sample ramets during the study and all flowers were wind pollinated. Between 1973 and 1976, from one to three successive crops of strobili were observed on the selected clones at monthly intervals from the time they were recognizable as flowers until they were collected as mature cones. Seeds extracted from the

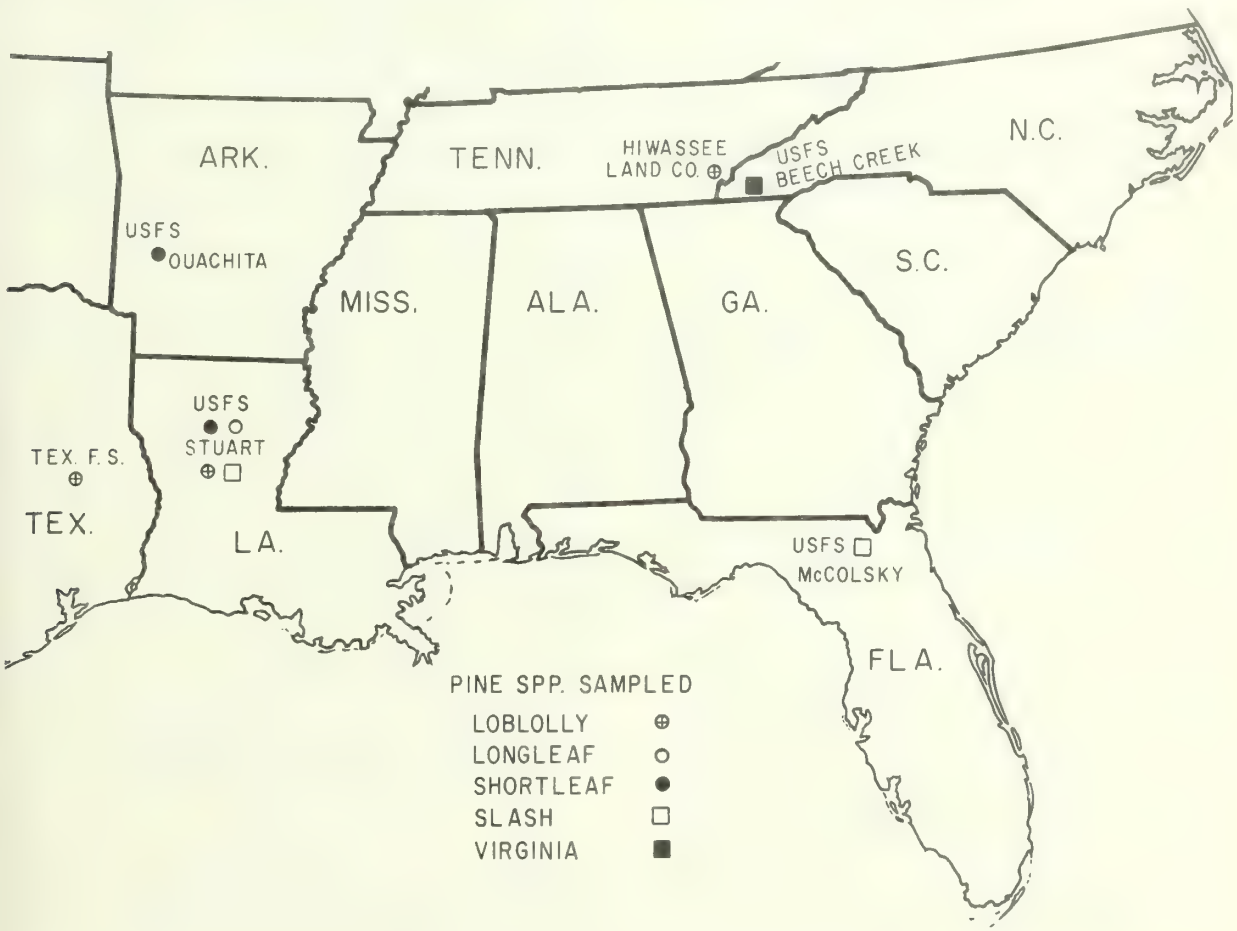

Figure 1.—Locations of the pine seed orchards surveyed.

Table 3.—Pine species, seed orchard location, year survey was initiated, and size of survey

Pine species and orchard	Year sampling began	No. clones sampled	No. ramets per sample clone	Total No. ramets sampled
Loblolly:				
Hiwassee (Tenn.)	1974	9	3	27
	1975	10	2–3	29
Magnolia Springs (Tex.)	1974	7	3–5	32
	1975	8	3–5	35
Stuart (La.)	1975	4	2	8
Longleaf:				
Stuart (La.)	1975	4	2	8
Shortleaf:				
Ouachita (Ark.)	1974	9	3	27
	1975	4	2	8
Stuart (La.)	1975	5	2	10
Slash:				
McColsky (Fla.)	1973	9	2	18
	1974	9	2	18
	1975	9	2	18
Stuart (La.)	1975	3	2	6
Virginia:				
Beech Creek (N.C.)	1974	10	2–4	30
	1975	10	2–4	30

Table 4.—Description of pine seed orchards included in the survey

Name of orchard	Species	Area of orchard	Avg. ramet age (1976)	Avg. d.b.h. (1976)	Avg. height (1976)	Spacing	Total clones	Total ramets	Soil type	Ground cover (grass)	Orchard establishment
		ha	*yr*	*cm*	*.....m*	.....		*.....No.*	.....		*yr*
Beech Creek	Virginia	16.6	8	7	6.6	4.6 × 9.1	10	484	Hayesville	Tall Kentucky 31 Fescue	1964–1971
Hiwassee	Loblolly	5.3	15	15	9.1	9.1 × 9.1	10	321	Clay base	Fescue	1960–1962
Magnolia Spring	Loblolly	2.2	9	23	10.1	8.5 × 9.1	20	229	Sandy loam	Bermuda	1966–1968
McColsky	Slash	2.1	18	30	15.5	9.1 × 9.1	9	207	Leon fine sandy loam	Carpet	1957–1959
Ouachita	Shortleaf	121.4	13	15	17.6	4.6 × 9.1	5	436	Hearndan & Goldstone mix	Lovegrass	1958–1968
Stuart	Loblolly	21.0	6	20	7.6	4.6 × 9.1	4	400	Sandy loam	Bahia	1967–1972
Stuart	Longleaf	3.4	6	13	7.0	4.6 × 9.1	4	67	Sandy loam	Bahia	1967–1972
Stuart	Shortleaf	16.4	6	14	6.1	4.6 × 9.1	5	389	Sandy loam	Bahia	1967–1972
Stuart	Slash	2.3	6	18	6.7	4.6 × 9.1	3	34	Sandy loam	Bahia	1967–1972

cones were radiographed to determine causes for unsound seed and germinated to determine viability.

A two-stage sampling design was used to estimate the numbers of female strobili present and seeds extracted from mature cones in each clone sampled. A clone was considered a natural stratification variable because of the genetic equality of ramets within clones and because the number of ramets per clone was known in each orchard. A minimum of two ramets per sample clone was selected at random within each orchard. Ramets were considered to be primary sampling units and clusters of female strobili were considered secondary (or listing) sampling units. Individual female strobili or seeds extracted from mature cones were considered to be the ultimate observational units. Estimates of the total numbers ($\hat{Y}$) of

female strobili for specified time periods and of seeds extracted from cones were produced for each clone sampled according to the formulas given in the Appendix. These estimates, however, were not calculated from sample strobili broken off, lost, or otherwise accidentally destroyed by man during monthly observations. Only the actual numbers of these strobili were included in the results.

Sampling Procedure Used for Strobili

The study was initiated in January 1973 at the McColsky slash pine seed orchard near Lake City, Florida. Two ramets of each of the nine clones in the orchard were selected at random. All of the female flower clusters on each ramet were counted and assigned a consecutive number by attaching a numbered tag to the branch immediately below each cluster.

A 20-percent sample of the tagged clusters on each ramet was selected at random. A piece of small copper wire was attached loosely around the stem of one of the flowers in each sample cluster. Using this flower as a reference, all other flowers within the same cluster were assigned consecutive numbers in a clockwise direction as viewed from the cluster toward the bole of the tree. This procedure facilitated making repeated monthly observations of individual strobili without having to attach tags to each of the individuals within a cluster. The condition[7] of each strobilus and the apparent cause for the condition observed were recorded. Damaged strobili or insects found infesting them were not collected since some insects are known to individually attack more than one strobilus, and the number of strobili attacked by individual insects of other species is unknown. Thus, removal of the insects, or strobili containing them, could have resulted in underestimating the total losses. This procedure probably led to higher estimates of mortality by unknown insects in cases where the observer was in doubt of the insect involved but recognized evidence of insect feeding on the strobili. Such evidence consisted of insect entry or exit holes, the presence of insect frass inside or outside the strobili, external feeding scars or wounds, or insects that could not be identified by the observer. Once all strobili within a cluster were dead, the tag was removed.

The sampling procedure was modified in 1974 because of the exorbitant amount of time required to initially tag all flower clusters on each ramet before selecting the sample clusters. At midcrown level, the four cardinal directions were marked with plastic flagging ribbon to denote the NE., SE., SW., and NW. quadrants of the crown. The total number of clusters in each quadrant was counted and recorded. Consecutively numbered tags were attached to a minimum of 10 percent of the clusters within each quadrant. If less than 10 clusters were present in a given quadrant, at least one of the clusters present was included in the sample. The sample clusters selected were spread as evenly as possible from the upper to lower crown in each quadrant. This procedure may have introduced some bias into the estimates because the sample clusters were not selected with equal probability within the crown of each ramet. Although strobili are generally not distributed at random within the crowns of southern pines, i.e., the majority of strobili are produced in the upper crown levels on the south and east sides of trees, insect attacks are generally at random within crowns except for a few insects known to concentrate their attacks within certain height levels of crowns (Coulson and Franklin 1968a; Coyne 1968; Smith and Stanley 1969; Yates and Ebel 1972; DeBarr and others 1975a). Attacks by coneworms, tip moths, and midges have been found to be concentrated in the upper crown levels of shortleaf and slash pines (Coulson and Franklin 1968a; Yates and Ebel 1972; DeBarr and others 1975a). Coyne (1968) found *L. ingens* Heinrich to prefer the lower crown levels of longleaf pine for oviposition. DeBarr and others (1975a) found no significant differences between the upper and lower crown levels of slash pine in the percentages of strobili infested by thrips and seedworms, or in the proportion of full, empty, and seed-bug damaged seed. Thus, the bias introduced by our nonrandom selection of sample clusters probably was of little consequence. The procedure did, however, ensure that observations were included from all height levels in the crowns of sample ramets. The number of flowers in each cluster was recorded and the flowers were identified as before by tying a piece of wire around the stem of one of them. Observations were made of the individual strobili at monthly intervals from the flower through the mature cone stages.

Sampling Procedure Used for Seeds

At harvest, cones were collected and stored

[7]The conditions of strobili were recorded as: Attacked (live), Attacked (dead), Distorted (live), Distorted (dead), Pitch present, Aborted (dead), Aborting (live), and Missing.

individually in paper bags labeled with each cone's identity. The times for cone harvest, the cone and seed treatment procedures, and the germination tests were based on information obtained from the National Forest Tree Seed Laboratory at Macon, Georgia.[8] After collection, cones were stored in well-ventilated rooms to prevent mold formation until the cone scales began to open. The cone scales were further opened by drying the cones in kilns or warm forced-air ovens for 24 hours at the following temperatures: longleaf pine cones, 44°C; loblolly, shortleaf, slash, and Virginia pine cones, 49°C.

The seeds were extracted by forcibly tapping the dried cones until seed no longer fell from them (first extraction). The cones were then cut along their longitudinal axes and the number of seedworm galleries within the cone axes were recorded as well as the number of seeds cut in half during bisection. The cones were then completely dissected to remove the remainder of the seed (second extraction). The seeds collected during each extraction process were stored separately in paper envelopes for each individual cone and processed separately.

The extracted seeds were radiographed to determine the numbers of seeds falling into the categories: full, empty, seed-bug damaged, seedworm damaged, and malformed. Radiographs were interpreted by using the criteria described by DeBarr (1970), Ebel and others (1975), and Bramlett and others (1977).

The radiographed seed were germinated to determine the numbers of viable seeds. Loblolly and shortleaf seeds were stratified before germination as follows: (1) seeds were soaked in water overnight; (2) the water was thoroughly drained from the seeds which were then placed in a plastic bag closed with a twist wire; (3) the bags were stored, with the seeds inside spread out in a single layer, at 2° to 3°C for 28 days; (4) once a week the bags were turned over to prevent water puddling; and (5) the seeds were air dried for about 1 hour at room temperature prior to germination tests. Seed germination tests were conducted in transparent plastic containers under photoperiods of about 8 hours light/day for longleaf, shortleaf, slash, and Virginia pine seeds, and 12 hours light/day for loblolly pine seeds. The total number of viable seed collected during the second extraction was adjusted by adding the number of cut seed expected to germinate if they had not been cut. The proportion of whole seed that germinated was used as an estimate of the proportion of cut seed expected to germinate for each cone.

Life Tables

Life tables were prepared for each generation of strobili observed during the study. The estimated number of strobili that died (d_x) during each month (x) is listed according to mortality factors (d_xF). The estimate, d_x, does not necessarily indicate the age at which strobili were initially attacked; it indicates the age at which strobili died after previously being attacked by the factor listed in the d_xF column. The estimated number of strobili remaining alive in the population at the beginning of each month (l_x) and the mortality rate for each factor are also listed. The mortality rate is expressed as a percentage of the number of strobili alive at the beginning of each age interval (q_x) and of the initial cohort of stobili present as flowers at the beginning of each generation (r_x).

RESULTS AND DISCUSSION

Some discrepancies were found in the occurrence of various mortality factors and their subsequent effect on strobili and seed of the same species of pines grown in different orchards. As the data utilized in this study were collected by more than 18 different observers, our estimates undoubtedly varied with each observer's ability to correctly identify the causes of damage symptoms on strobili and on radiographs of seeds. Multiple attacks by different species of insects on the same strobili could also have resulted in discrepancies in damage estimates when the damage symptoms of an initially attacking insect were obliterated by a later attack, e.g., feeding by coneworms on second-year cones could obliterate seed-bug damage to extracted seeds. The remainder of these discrepancies was probably due to differences between years, localities, insect population levels, and susceptibilities of different clones to insect attacks. In general, estimates of total losses of strobili and seed showed less variability than those for individual mortality factors, i.e., the coefficients of variation were lower for total losses than for individual mortality factors.

Mortality of Strobili

The estimated total losses of strobili varied widely between orchards, species of pines, and years (tables 5–9). The average total losses for each of the five species of pines surveyed were as

[8]Personal communication with Dr. Earl Belcher.

Table 5.—Estimated total mortality and coefficient of variation (C.V.) for loblolly pine strobili surveyed from 1974 to 1976

Mortality factor	Hiwassee orchard, Tennessee						Magnolia Springs orchard, Texas						Stuart orchard, Louisiana		
	1974-1975			1975-1976			1974-1975			1975-1976			1975-1976		
	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C. V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)
Coneworms	2,670	7.0	20.1	2,208	3.3	37.3	3,136	10.2	17.8	5,949	10.1	9.8	4,636	16.5	40.3
Coneworms (shoot)	—	—	—	—	—	—	28	.1	98.2	—	—	—	—	—	—
Looper	—	—	—	—	—	—	—	—	—	—	—	—	4,896	17.4	64.3
May beetle	—	—	—	—	—	—	—	--	—	—	—	—	32	.1	98.4
Pityophthorus sp.[a]	—	—	—	—	—	—	462	1.5	30.4	1,617	2.7	18.1	—	—	—
Tip moth	—	—	—	—	—	—	—	—	—	—	—	—	191	.7	74.1
Unknown insects	—	—	—	3,507	5.2	24.0	28	.1	98.2	1,617	2.7	20.2	2,338	8.3	39.0
Aborted	4,915	13.0	20.0	13,469	20.0	12.2	1,023	3.3	22.3	12,119	20.6	10.8	—	—	—
Man[b]	22	.1	—	33	(c)	—	90	.3	—	172	.3	—	8	(c)	—
Weather	490	1.3	75.7	—	—	—	—	—	—	—	—	—	—	—	—
Missing	7,537	19.9	13.4	11,820	17.6	19.4	4,571	14.9	13.9	5,632	9.6	12.2	955	3.4	27.7
Unknown	—	—	—	972	1.4	82.1	142	.5	42.7	—	—	—	819	2.9	24.2
Unknown fungus	—	—	—	—	—	—	24	.1	97.9	82	.1	60.4	—	—	—
Total loss	15,634	41.3	10.4	32,009	47.5	1.0	9,504	30.9	9.4	27,188	46.1	6.1	13,875	49.4	27.2
Total initial flowers	37,940	—	10.7	67,349	—	9.9	30,764	—	10.8	58,948	—	5.2	28,098	—	8.2

[a]The primary nature of this insect's attack is subject to question.
[b]C.V. not calculated because figures listed are parameters.
[c]Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

Table 6.—Estimated total mortality and coefficient of variation (C.V.) for longleaf pine strobili surveyed from 1975 to 1976

Mortality factor	Stuart orchard, Louisiana, 1975–1976		
	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)
Coneworms	611	16.1	12.6
Unknown insects	2,326	61.2	22.2
Aborted	40	1.1	98.5
Mana	1	(b)	—
Missing	152	4.0	58.6
Unknown	148	3.9	50.0
Total loss	3,278	86.2	16.4
Total initial flowers	3,801	—	14.0

[a]C.V. not calculated because figure listed is a parameter.
[b]Less than 0.05 percent.
Computer totals truncated to nearest thousandth.

follows: (1) loblolly pine, 43.0 percent; (2) longleaf pine, 86.2 percent; (3) shortleaf pine, 80.8 percent; (4) slash pine, 55.1 percent; and (5) Virginia pine, 53.2 percent. In general more than half (30.9 to 90.3 percent) of the strobili initially present as flowers were lost before cone harvest.

The 15 life tables developed for pine strobili during this study are summarized in tables 10 to 14. These cohort or generation-type life tables (Waters 1969) provide records of the age structure of strobilus mortality throughout development from flowers to mature cones. An initial cohort of 10,000 flowers was arbitrarily chosen for these tables to facilitate interpretation of the life table data. The mortality rates (r_x) were averaged over all crops of strobili for each species of pine to illustrate the approximate mortalities incurred at monthly intervals from the flower stage to cone harvest. Thus, tables 10 to 14 represent average life tables for each species of pine. The rate of strobilus mortality is illustrated as survivorship curves and the life table data are further summarized into three developmental periods according to the classification system proposed by Croker (1971) for female strobili of southern pines: (1) flowers to early conelets, (2) early conelets to green cones, and (3) green cones to ripe cones (figs. 2–6).

Flower to Early Conelet Stages

The major losses of strobili of all species occurred during their first year of development in all of the orchards surveyed (figs. 2–6). In 13 of the 15 cone crops observed, the heaviest mortality occurred in the first 3 to 5 months of development from flowers to early conelets, i.e., between January and June. During this interval, 9.7 to 81.9 percent of the initial strobili died which represented an average of 58.8 percent of the total mortality observed throughout strobilus development.

Strobilus abortion was observed in all orchards except on loblolly or slash pine in the Stuart orchard or the 1975–1976 cone crop of shortleaf pine in the Ouachita orchard. As strobilus abortion occurs over a short period of time and aborted strobili fall from the trees, a large proportion of those strobili listed as missing between observations is assumed to have aborted. The causes for abortion of flowers and early conelets were not determined during this study.

Early spring frosts resulted in 0.3 to 2.7 percent mortality of flowers in the loblolly pine orchard in Tennessee and the Virginia pine orchard in North Carolina. An additional 28.7 percent of the Virginia pine flowers was lost following hail damage during April 1975 in the North Carolina orchard. Weather was not reported as a mortality factor in the orchards located in lower latitudes.

Insect damage was associated with an average of 14.1 percent (0 to 51.1 percent) of the initial strobili lost during this period. Coneworms were found in all orchards surveyed but were not reported to damage flowers or early conelets of

Table 7.—Estimated total mortality and coefficient of variation (C.V.) for shortleaf pine strobili surveyed from 1974 to 1976

Mortality factor	Ouachita orchard, Arkansas						Stuart orchard, Louisiana		
	1974-1975			1975-1976			1975-1976		
	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)
Coneworms	3,065	4.4	27.4	1,178	8.0	33.3	376	0.4	81.6
Coneworms (shoot)	525	.7	59.5	—	—	—	—	—	—
May beetle	88	.1	98.3	—	—	—	390	.4	99.9
Tip moth	31,341	44.6	11.2	2,458	16.7	16.7	1,014	1.2	99.0
Unknown insects	5,254	7.5	19.7	2,207	15.0	41.9	24,245	27.9	16.6
Aborted	14,889	21.2	15.3	—	—	—	4,162	4.8	26.3
Man[a]	60	.1	—	—	—	—	12	(b)	—
Missing	7,705	11.0	18.2	6,505	44.2	25.8	25,691	29.6	21.7
Unknown	594	.8	46.9	—	—	—	3,191	3.7	67.3
Total loss	63,521	90.4	7.9	12,348	83.9	16.2	59,081	68.0	12.5
Total initial flowers	70,310	—	11.5	14,713	—	16.6	86,867	—	15.0

[a]C.V. not calculated as figures listed are parameters.
[b]Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

Table 8.—Estimated total mortality and coefficient of variation (C.V.) for slash pine strobili surveyed from 1973 to 1976

Mortality factor	McColsky orchard, Florida									Stuart orchard, Louisiana		
	1973-1974			1974-1975			1975-1976			1975-1976		
	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)
Coneworms	8,378	13.9	17.6	8,166	8.8	20.5	22,630	31.6	10.5	1,542	38.7	45.9
Coneworms (shoot)	1,219	2.0	33.4	2,827	3.1	25.2	685	1.0	34.8	—	—	—
Thrips	775	1.3	36.2	18,221	19.7	21.9	13,227	18.5	21.8	—	—	—
Unknown insects	401	.7	37.5	311	.3	58.2	—	—	—	909	22.8	25.3
Weevil	120	.2	99.2	—	—	—	—	—	—	—	—	—
Aborted	4,328	7.2	10.8	9,601	10.4	26.6	1,837	2.6	41.2	—	—	—
Cone rust	112	.2	70.1	—	—	—	224	.3	97.5	—	—	—
Man[a]	34	.1	—	22	(b)	—	6	(b)	—	1	(b)	—
Missing	5,734	9.5	16.2	6,208	6.7	15.5	4,812	6.7	20.5	282	7.1	56.8
Unknown	927	1.5	27.3	466	.5	35.4	1,385	1.9	36.6	140	3.5	61.1
Total loss	22,028	36.5	8.7	45,822	49.5	11.3	44,806	62.5	8.8	2,874	72.1	27.1
Total initial flowers	60,368	—	9.7	92,653	—	9.4	71,654	—	7.5	3,987	—	20.8

[a]C.V. not calculated because figures listed are parameters.
[b]Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

Table 9.—Estimated total mortality and coefficient of variation (C.V.) for Virginia pine strobili surveyed from 1974 to 1976

Mortality factor	Beech Creek orchard, North Carolina					
	1974–1975			1975–1976		
	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)	No. of strobili ($\hat{Y}$)	% of initial flowers	C.V. (%)
Coneworms	181	0.5	99.7	351	0.7	98.0
Unknown insects	587	1.6	53.8	1,359	2.9	40.1
Aborted	15,012	41.2	15.4	1,963	4.2	30.5
Hail	—	—	—	13,472	28.7	18.1
Man[a]	14	(b)	—	11	(b)	—
Weather	967	2.7	52.2	162	.3	99.7
Missing	7,197	19.7	19.9	1,597	3.4	29.6
Unknown	—	—	—	220	.5	98.0
Total loss	23,958	65.7	11.7	19,135	40.7	14.0
Total initial flowers	36,450	—	12.3	46,993	—	10.8

[a]C.V. not calculated because figures listed are parameters.
[b]Less than 0.05 percent.

Virginia pine in the Beech Creek orchard or of the shortleaf pine during 1975 in the Ouachita orchard. Direct attacks on strobili by coneworms resulted in 0.1 to 23.3 percent mortality in the other orchards during this period and an additional 0.1 to 2.1 percent of the strobili were killed as a result of shoot attacks by coneworms in three of the orchards. In general, coneworms caused minor damage (0.2 to 3.6 percent) during the flower and early conelet stages in all but one of the orchards. In the spring of 1975, coneworms killed 23.3 percent of the slash pine strobili in the Stuart orchard.

Tip moths destroyed 1.2 to 44.4 percent of the flowers and early conelets in both of the shortleaf pine orchards surveyed and also were reported to destroy 0.7 percent of the loblolly strobili during the spring of 1975 in the Stuart orchard. Loopers were found only on loblolly pine at the Stuart orchard where they were the major cause of mortality and destroyed 17.4 percent of the strobili between February and April. May beetles destroyed up to 0.4 percent of the loblolly and shortleaf pine strobili and *Pityophthorus* sp. was recorded only on loblolly pine in the Magnolia Springs orchard where the insect was found infesting 0.2 to 0.5 percent of the strobili. The *Pityophthorus* sp. infestations may have been secondary attacks following conelet death due to other causes.

Thrips damage was reported on slash pine in Florida and resulted in 1.3 to 18.4 percent mortality of the flowers and early conelets. Thripslike damage has been reported on flowers of loblolly pine (Goyer and Nachod 1976). Flowers fatally attacked by thrips dry out rapidly and fall from the trees in a manner similar to that of aborted cones. Thus, it is possible that thrips attacks may be responsible for part of the losses attributed to the abortion and missing categories for slash and loblolly pines in this study.

Attacks by unknown insects were observed in all orchards during this period and accounted for up to 17.3 percent mortality of the strobili. The first of two major peaks of mortality for strobili of longleaf pine occurred from February to June (fig. 3). During this first peak, unknown insects were associated with the loss of 17.5 percent of the longleaf pine strobili, coneworms destroyed 2.9 percent of them, 2.5 percent were missing, and 1.1 percent were found dead from unknown causes. The unknown insect category may also have included attacks by secondary insects on strobili dead or dying from other causes.

Table 10.—Life table of loblolly pine strobili in Hiwassee (Tenn.), Magnolia Springs (Tex.), and Stuart (La.) seed orchards, 1974–1976

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
First year					
Jan.–Feb.	10,000	None	0	0	0
Feb.–Mar.	10,000	Coneworms	5	.046	.046
		Looper	85	.847	.847
		Man	<1	.002	.002
		May beetle	2	.023	.023
		Missing	2	.023	.023
		Unknown insects	20	.204	.204
		Unknown	19	.192	.192
		Subtotal	134	1.337	1.337
Mar.–Apr.	9,866	Abortion	175	1.778	1.754
		Coneworms	2	.022	.022
		Looper	264	2.674	2.638
		Man	3	.032	.032
		Missing	263	2.662	2.626
		Pityophthorus sp.[a]	4	.043	.042
		Tip moth	14	.138	.136
		Unknown insects	71	.715	.705
		Unknown	2	.020	.020
		Weather	13	.136	.134
		Subtotal	811	8.219	8.109
Apr.–May	9,055	Abortion	593	6.549	5.930
		Coneworms	9	.094	.085
		Man	2	.025	.023
		Missing	497	5.485	4.967
		Pityophthorus sp.[a]	8	.087	.079
		Unknown	7	.073	.066
		Subtotal	1,115	12.313	11.150
May–June	7,940	Abortion	45	.564	.448
		Coneworms	88	1.111	.882
		Man	<1	.005	.004
		Missing	113	1.421	1.128
		Pityophthorus sp.[a]	14	.170	.135
		Unknown fungus	2	.024	.019
		Unknown insects	54	.681	.541
		Subtotal	316	3.976	3.157

Continued

Table 10.—Life table of loblolly pine strobili in Hiwassee (Tenn.), Magnolia Springs (Tex.), and Stuart (La.) seed orchards, 1974–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
June–July	7,625	Abortion	9	.113	.086
		Coneworms	145	1.900	1.449
		Man	1	.007	.005
		Missing	68	.891	.679
		Weather	12	.163	.124
		Subtotal	234	3.073	2.343
July–Aug.	7,390	Abortion	14	.193	.143
		Coneworms	79	1.068	.789
		Man	<1	.003	.002
		Missing	86	1.157	.855
		Pityophthorus sp.[a]	4	.051	.038
		Unknown fungus	1	.012	.009
		Unknown insects	3	.042	.031
		Subtotal	187	2.526	1.867
Aug.–Sept.	7,204	Abortion	81	1.120	.087
		Coneworms	102	1.415	1.019
		Man	<1	004	.003
		Missing	87	1.205	.868
		Pityophthorus sp.[a]	3	.042	.030
		Unknown insects	32	.441	.318
		Unknown	6	.079	.057
		Subtotal	310	4.306	3.102
Sept.–Oct.	6,894	Abortion	156	2.269	1.564
		Coneworms	37	.534	.368
		Man	1	.016	.011
		Missing	43	.619	.427
		Pityophthorus sp.[a]	14	.196	.135
		Unknown insects	36	.519	.358
		Unknown	1	.012	.008
		Subtotal	287	4.165	2.871
Oct.–Nov.	6,606	Abortion	11	.171	.113
		Coneworms	35	.536	.354
		Man	<1	.001	<.001
		Missing	27	.410	.271
		Pityophthorus sp.[a]	5	.073	.048
		Unknown insects	3	.044	.029
		Subtotal	82	1.234	.815

Continued

Table 10.—Life table of loblolly pine strobili in Hiwassee (Tenn.), Magnolia Springs (Tex.), and Stuart (La.) seed orchards, 1974–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
Nov.–Dec.	6,525	Abortion	1	.014	.009
		Coneworms	6	.097	.063
		Man	<1	.002	.001
		Missing	3	.052	.034
		Subtotal	11	.164	.107
Dec.–Jan.	6,514	Abortion	1	.017	.011
		Man	<1	.001	<.001
		Missing	9	.135	.088
		Subtotal	10	.153	.099
Second year					
Jan.–Feb.	6,504	Abortion	4	.055	.036
		Coneworms	8	.125	.081
		Man	<1	.003	.002
		Missing	19	.298	.194
		Pityophthorus sp.[a]	8	.129	.084
		Subtotal	40	.610	.397
Feb.–Mar.	6,465	Abortion	8	.124	.080
		Coneworms	11	.173	.112
		Man	3	.053	.034
		Missing	7	.108	.070
		Pityophthorus sp.[a]	6	.093	.060
		Unknown insects	7	.105	.068
		Subtotal	42	.658	.424
Mar.–Apr.	6,422	Abortion	12	.188	.121
		Coneworms	14	.215	.138
		Man	<1	.002	.001
		Missing	7	.115	.074
		Pityophthorus sp.[a]	12	.187	.120
		Unknown insects	95	1.473	.946
		Subtotal	140	2.180	1.400
Apr.–May	6,282	Abortion	2	.030	.019
		Coneworms	51	.810	.509
		Man	1	.014	.009
		Missing	36	.565	.355
		Pityophthorus sp.[a]	8	.123	.077
		Unknown insects	3	.048	.030
		Subtotal	100	1.590	.999

Continued

Table 10.—Life table of loblolly pine strobili in Hiwassee (Tenn.), Magnolia Springs (Tex.), and Stuart (La.) seed orchards, 1974–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
May–June	6,182	Abortion	2	.026	.016
		Coneworms	139	2.255	1.394
		Man	<1	.002	.001
		Missing	14	.218	.135
		Unknown fungus	2	.026	.016
		Unknown insects	4	.071	.044
		Unknown	3	.045	.028
		Subtotal	163	2.643	1.634
June–July	6,019	Coneworms	22	.361	.217
		Man	<1	.002	.001
		Missing	2	.032	.019
		Subtotal	24	.394	.237
July–Aug.	5,995	Abortion	17	.284	.170
		Coneworms	20	.340	.204
		Man	<1	.002	.001
		Missing	17	.275	.165
		Unknown insects	1	.022	.013
		Unknown	30	.504	.302
		Subtotal	86	1.426	.855
Aug.–Sept.	5,910	Abortion	4	.069	.041
		Coneworms	136	2.300	1.359
		Man	<1	.002	.001
		Missing	6	.100	.059
		Unknown	9	.151	.089
		Subtotal	155	2.621	1.549
Sept.–Oct.	5,755	Abortion	2	.033	.019
		Coneworms	15	.254	.146
		Man	1	.014	.008
		Missing	1	.016	.009
		Unknown	20	.349	.201
		Subtotal	38	.666	.383
Harvest	5,717				

[a]Whether infestation by this insect caused strobilus mortality is subject to question.

Computer totals truncated to nearest thousandth.

Table 11.—Life table of longleaf pine strobili in the Stuart (La.) seed orchard, 1975–1976

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
First year					
Jan.–Feb.	10,000	Unknown	66	0.658	0.658
Feb.–Mar.	9,934	Abortion	105	1.059	1.052
		Coneworms	121	1.218	1.210
		Unknown insects	32	.318	.316
		Unknown	113	1.138	1.131
		Subtotal	371	3.734	3.709
Mar.–Apr.	9,563	Coneworms	61	.633	.605
		Unknown insects	637	6.658	6.367
		Subtotal	697	7.290	6.972
Apr.–June[a]	8,866	Coneworms	111	1.246	1.105
		Missing	253	2.849	2.526
		Unknown insects	1,060	11.958	10.602
		Subtotal	1,423	16.053	14.233
June–July	7,443	None	0	0	0
July–Aug.	7,443	Coneworms	176	2.369	1.763
Aug.–Sept.	7,267	Coneworms	637	8.762	6,367
		Man	3	.036	.026
		Unknown insects	1,610	22.156	16.101
		Unknown	179	2.462	1.789
		Subtotal	2,428	33.415	24.283
Sept.–Oct.	4,839	Coneworms	382	7.884	3.815
		Missing	105	2.174	1.052
		Unknown insect	2,434	50.295	24.336
		Subtotal	2,920	60.353	29.203
Oct.–Nov.	1,918	Unknown insects	124	6.448	1.237
Second year					
Nov.–Feb.[a]	1,795	Unknown insects	97	5.422	.973
		Unknown	32	1.761	.316
		Subtotal	129	7.183	1.289
Feb.–Apr.[a]	1,666	Coneworms	61	3.633	.605
		Unknown insects	126	7.583	1.263
		Subtotal	187	11.126	1.868

Continued

Table 11.—Life table of longleaf pine strobili in the Stuart (La.) seed orchard, 1975–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
Apr.–May	1,479	None	0	0	0
May–June	1,479	Missing	42	2.847	.421
June–July	1,437	None	0	.000	.000
July–Aug.	1,437	None	0	.000	.000
Aug.–Sept.	1,437	Coneworms	61	4.212	.605
Sept.–Oct.	1,376	None	0	0	0
Harvest	1,376				

[a]Observations were not taken during May and December 1975 and during January and March 1976.

Computer totals truncated to nearest thousandth.

Table 12.—Life table of shortleaf pine strobili in the Ouachita (Ark.) and Stuart (La.) seed orchards, 1974–1976

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
First year					
Jan.–Feb.	10,000	Abortion	6	0.060	0.060
		Coneworms	12	.124	.124
		Man	<1	.001	.001
		Tip moths	3	.028	.028
		Subtotal	21	.213	.213
Feb.–Mar.	9,979	Abortion	647	6.488	6.474
		Coneworms	13	.125	.125
		Man	1	.011	.011
		Missing	40	.396	.395
		Tip moths	75	.752	.750
		Unknown insects	65	.651	.650
		Unknown	94	.937	.935
		Subtotal	934	9.360	9.340

Continued

Table 12.—Life table of shortleaf pine strobili in the Ouachita (Ark.) and Stuart (La.) seed orchards, 1974–1976 — Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
Mar.–Apr.	9,045	Abortion	209	2.312	2.091
		Coneworms	7	.078	.071
		Man	<1	.003	.003
		Maybeetle	4	.046	.042
		Missing	769	8.498	7.686
		Tip moths	1,363	15.066	13.627
		Unknown insects	390	4.315	3.903
		Unknown	7	.081	.073
		Subtotal	2,750	30.400	27.496
Apr.–May	6,295	Man	1	.011	.007
		Missing	317	5.036	3.170
		Unknown insects	21	.335	.211
		Subtotal	339	5.382	3.388
May–June	5,956	Abortion	1	.024	.014
		Coneworms	16	.272	.162
		Man	<1	.002	.001
		Maybeetle	15	.252	.150
		Missing	1,208	20.275	12.076
		Tip moths	637	10.695	6.370
		Unknown insects	222	3.731	2.222
		Unknown	13	.218	.130
		Subtotal	2,113	35.469	21.125
June–July	3,844	Abortion	2	.044	.017
		Man	<1	.005	.002
		Missing	20	.510	.196
		Tip moths	3	.086	.033
		Unknown insects	51	1.327	.510
		Unknown	3	.078	.030
		Subtotal	79	2.050	.788
July–Aug.	3,765	Coneworms	24	.627	.236
		Man	<1	.001	<.001
		Missing	55	1.464	.551
		Tip moths	1	.024	.009
		Unknown insects	251	6.665	2.509
		Subtotal	331	8.781	3.305

Continued

Table 12.—Life table of shortleaf pine strobili in the Ouachita (Ark.) and Stuart (La.) seed orchards, 1974–1976 — Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
Aug.–Sept.	3,434	Coneworms	133	3.873	1.330
		Missing	337	9.822	3.373
		Unknown insects	289	8.427	2.894
		Subtotal	760	22.123	7.597
Sept.–Oct.	2,674	Man	<1	.001	<.001
		Unknown insects	223	8.335	2.229
		Subtotal	223	8.336	2.229
Oct.–Nov.	2,451	Man	<1	.012	.003
		Missing	44	1.787	.438
		Unknown insects	78	3.166	.776
		Subtotal	122	4.965	1.217
Nov.–Dec.	2,330	Unknown insects	17	.721	.168
		Unknown	32	1.374	.320
		Subtotal	49	2.095	.488
Dec.–Jan.	2,281	Man	<1	.013	.003
		Missing	3	.123	.028
		Subtotal	3	.136	.031
Second year					
Jan.–Feb.	2,278	None	0	0	0
Feb.–Mar.	2,278	None	0	0	0
Mar.–Apr.	2,278	Missing	3	.149	.034
		Unknown insects	18	.795	.181
		Unknown	2	.079	.018
		Subtotal	23	1.023	.233
Apr.–May	2,255	Coneworms	129	5.726	1.291
		Man	<1	.001	<.001
		Missing	16	.692	.156
		Unknown insects	54	2.395	.540
		Subtotal	199	8.814	1.987
May–June	2,056	None	0	0	0
June–July	2,056	Coneworms	20	.968	.199
July–Aug.	2,036	Coneworms	78	3.821	.778
Aug.–Sept.	1,958	Coneworms	20	1.016	.199
Sept.–Oct.	1,938	Missing	15	.758	.147
Harvest	1,924				

Computer totals truncated to nearest thousandth.

Table 13.—Life table of slash pine strobili in the McColsky (Fla.) and Stuart (La.) seed orchards, 1973–1976

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
First year					
Jan.–Feb.	10,000	Abortion	49	0.487	0.487
		Coneworms	138	1.380	1.380
		Man	<1	.003	.003
		Missing	18	.181	.181
		Thrips	276	2.761	2.761
		Unknown insects	2	.022	.022
		Unknown	3	.032	.032
		Subtotal	487	4.866	4.866
Feb.–Mar.	9,513	Abortion	69	.722	.687
		Coneworms	255	2.679	2.549
		Man	<1	.003	.033
		Missing	112	1.181	1.124
		Thrips	560	5.884	5.598
		Unknown insects	131	1.378	1.311
		Unknown	16	.167	.159
		Weevil	5	.053	.050
		Subtotal	1,148	12.068	11.481
Mar.–Apr.	8,365	Abortion	87	1.035	.866
		Coneworms	137	1.642	1.374
		Man	<1	.004	.003
		Missing	173	2.063	1.726
		Thrips	70	.842	.704
		Unknown insects	36	.430	.360
		Subtotal	503	6.017	5.033
Apr.–May	7,862	Abortion	112	1.426	1.121
		Cone rust	8	.099	.078
		Coneworms	69	.874	.687
		Man	<1	.001	.001
		Missing	186	2.371	1.864
		Thrips	27	.346	.272
		Unknown insects	35	.439	.345
		Subtotal	437	5.556	4.368
May–June	7,425	Cone rust	5	.063	.047
		Coneworms	340	4.578	3.399
		Man	<1	.003	.002
		Missing	62	.835	.620
		Thrips	23	.307	.228
		Subtotal	430	5.786	4.296

Continued

Table 13.—Life table of slash pine strobili in the McColsky (Fla.) and Stuart (La.) seed orchards, 1973–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
June–July	6,996	Abortion	56	.806	.564
		Coneworms	341	4.872	3.408
		Man	<1	.001	.001
		Missing	18	.254	.178
		Unknown	31	.440	.308
		Subtotal	446	6.374	4.459
July–Aug.	6,550	Abortion	49	.754	.494
		Coneworms	88	1.336	.875
		Man	<1	.002	.001
		Missing	19	.287	.188
		Thrips	13	.203	.133
		Subtotal	169	2.582	1.691
Aug.–Sept.	6,381	Coneworms	373	5.840	3.726
		Man	<1	.002	.001
		Missing	14	.218	.139
		Thrips	4	.058	.037
		Unknown insects	154	2.407	1,536
		Unknown	92	1.447	.923
		Subtotal	636	9.971	6.362
Sept.–Oct.	5,744	Abortion	24	.411	.236
		Coneworms	174	3.033	1.742
		Man	<1	.007	.004
		Missing	34	.597	.343
		Unknown insects	193	3.362	1.931
		Subtotal	426	7.409	4.256
Oct.–Nov.	5,319	Abortion	2	.043	.023
		Coneworms	10	.186	.099
		Man	<1	.002	.001
		Missing	4	.077	.041
		Unknown insects	16	.295	.157
		Unknown	4	.077	.041
		Subtotal	36	.681	.362
Nov.–Dec.	5,283	Abortion	7	.136	.072
		Coneworms	35	.666	.352
		Missing	8	.150	.079
		Unknown	6	.108	.057
		Subtotal	56	1.060	.560

Continued

Table 13.—Life table of slash pine strobili in the McColsky (Fla.) and Stuart (La.) seed orchards, 1973–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
Dec.–Jan.	5,227	Abortion	3	.052	.027
		Coneworms	4	.078	.041
		Man	1	.013	.007
		Missing	4	.075	.039
		Subtotal	11	.218	.114
Second year					
Jan.–Feb.[a]	5,215	Abortion	3	.048	.025
		Coneworms	2	.046	.024
		Missing	8	.148	.077
		Subtotal	13	.242	.126
Feb.–Mar.	5,203	Abortion	11	.204	.106
		Coneworms	13	.258	.134
		Man	<1	<.001	<.001
		Subtotal	24	.462	.240
Mar.–Apr.	5,179	Coneworms	13	.253	.131
		Man	<1	.002	.001
		Thrips	6	.116	.060
		Unknown	3	.058	.030
		Unknown insects	23	.436	.226
		Subtotal	45	.865	.448
Apr.–May	5,134	Abortion	17	.335	.172
		Coneworms	84	1.632	.838
		Man	<1	.002	.001
		Missing	12	.240	.123
		Unknown insects	3	.064	.033
		Subtotal	117	2.273	1.167
May–June	5,017	Coneworms	95	1.889	.948
		Unknown	23	.456	.229
		Subtotal	118	2.346	1.177
June–July	4,900	Abortion	10	.196	.096
		Coneworms	217	4.423	2.167
		Missing	26	.533	.261
		Thrips	6	.125	.061
		Unknown	3	.067	.033
		Subtotal	262	5.343	2,618

Continued

Table 13.—Life table of slash pine strobili in the McColsky (Fla.) and Stuart (La.) seed orchards, 1973–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
July–Aug.	4,638	Coneworms	76	1.643	.762
		Man	<1	.002	.001
		Missing	40	.869	.403
		Unknown	6	.134	.062
		Subtotal	123	2.648	1.228
Aug.–Sept.	4,515	Abortion	5	.109	.049
		Coneworms	11	.244	.110
		Missing	11	.252	.114
		Unknown insects	3	.066	.030
		Subtotal	30	.671	.303
Harvest	4,485				

Computer totals truncated to nearest thousandth.

Table 14.—Life table of Virginia pine strobili in the Beech Creek (N.C.) seed orchard, 1974–1976

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
First year					
Feb.–Mar.	10,000	None	0	0	0
		Subtotal	0	0	0
Mar.–Apr.	10,000	Abortion	223	2.232	2.232
		Missing	181	1.808	1.808
		Subtotal	404	4.040	4.040
Apr.–May	9,596	Abortion	1,375	14.327	13.748
		Man	<1	.003	.003
		Missing	497	5.176	4.967
		Weather	1,583	16.500	15.833
		Subtotal	3,455	36.006	34.551
May–June	6,141	Abortion	198	3.218	1.976
		Missing	223	3.631	2.230
		Unknown insects	90	1.467	.901
		Subtotal	511	8.316	5.107

Continued

Table 14.—Life table of Virginia pine strobili in the Beech Creek (N.C.) seed orchard, 1974–1976—Continued

Age interval in months (x)	Number of strobili alive at beginning of x (l_x)	Mortality factor (d_xF)	Number of strobili dying during x (d_x)	Mortality rate d_x as a percent of l_x ($100q_x$)	Mortality rate d_x as a percent of initial l_x ($100r_x$)
June–July	5,630	Abortion	24	.433	.244
		Man	<1	.004	.002
		Missing	107	1.893	1.066
		Subtotal	131	2.330	1.312
July–Aug.	5,499	Abortion	244	4.443	2.443
		Missing	21	.376	.207
		Unknown	23	.426	.234
		Subtotal	288	5.245	2.884
Aug.–Sept.	5,211	Abortion	204	3.913	2.039
		Coneworms	37	.718	.374
		Man	1	.015	.008
		Missing	21	.397	.207
		Subtotal	263	5.044	2.628
Sept.–Oct.	4,948	Man	2	.044	.022
Oct.–Nov.	4,946	Missing	66	1.343	.664
Nov.–Dec.	4,879	None	0	0	0
Dec.–Jan.	4,879	None	0	0	0
Second year					
Jan.–Feb.	4,879	None	0	0	0
Feb.–Mar.	4,879	None	0	0	0
Mar.–Apr.	4,879	Missing	76	1.547	.755
		Unknown insects	55	1.117	.545
		Subtotal	130	2.664	1.300
Apr.–May	4,749	None	0	0	0
May–June	4,749	Unknown insects	7	.139	.066
June–July	4,743	Coneworms	25	.525	.249
		Unknown insects	74	1.560	.740
		Subtotal	99	2.085	.989
July–Aug.	4,644	None	0	0	0
Aug.–Sept.	4,644	Man	1	.015	.007
Harvest	4,643				

Computer totals truncated to nearest thousandth.

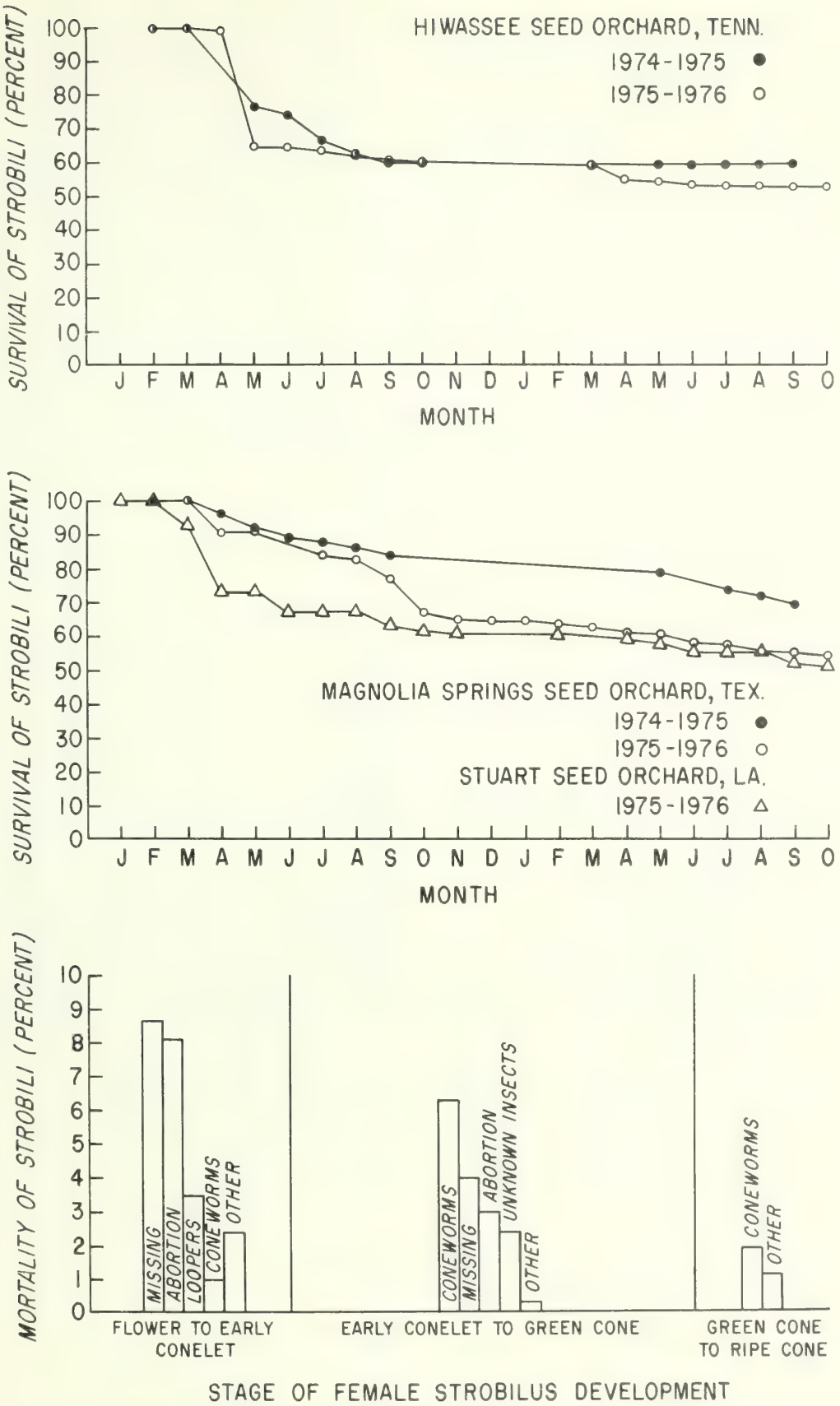

Figure 2.—Survival curves and the average mortality due to different factors for strobili of loblolly pine in three seed orchards from 1974 to 1976.

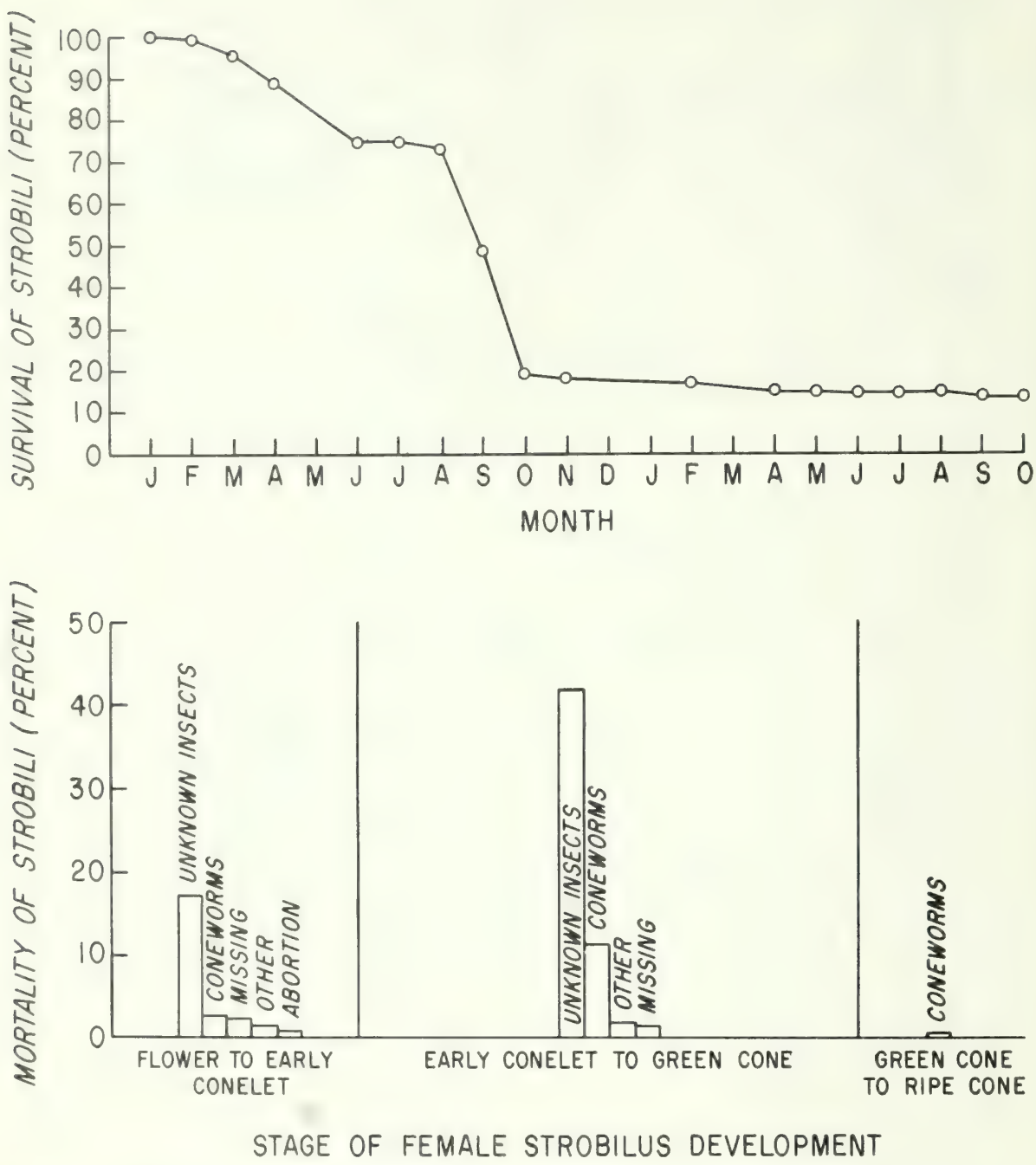

Figure 3.—Survival curve and the average mortality due to different factors for strobili of longleaf pine in the Stuart (La.) seed orchard from 1975 to 1976.

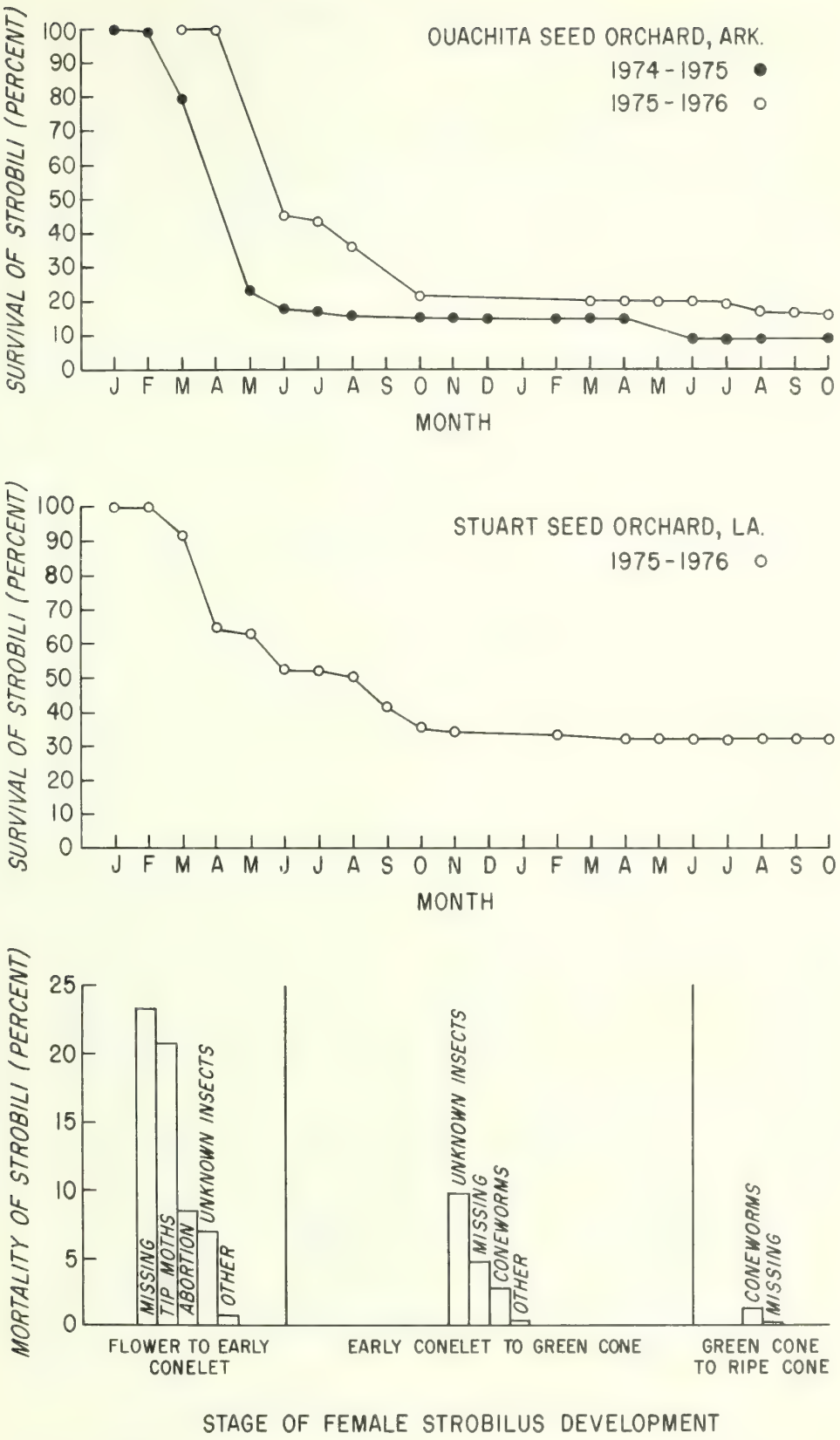

Figure 4.—Survival curves and the average mortality due to different factors for strobili of shortleaf pine in two seed orchards from 1974 to 1976.

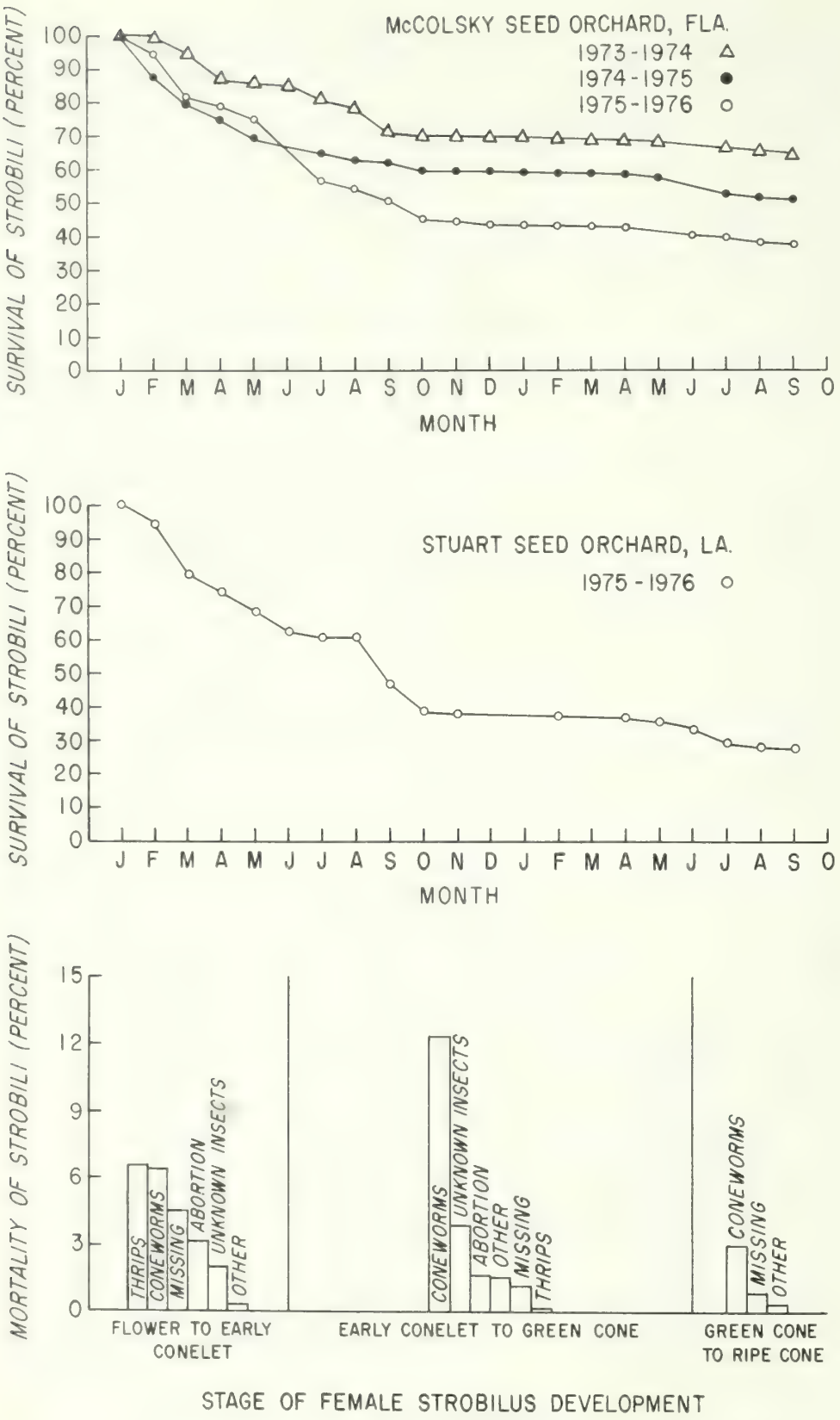

Figure 5.—Survival curves and the average mortality due to different factors for strobili of slash pine in two orchards from 1973 to 1976.

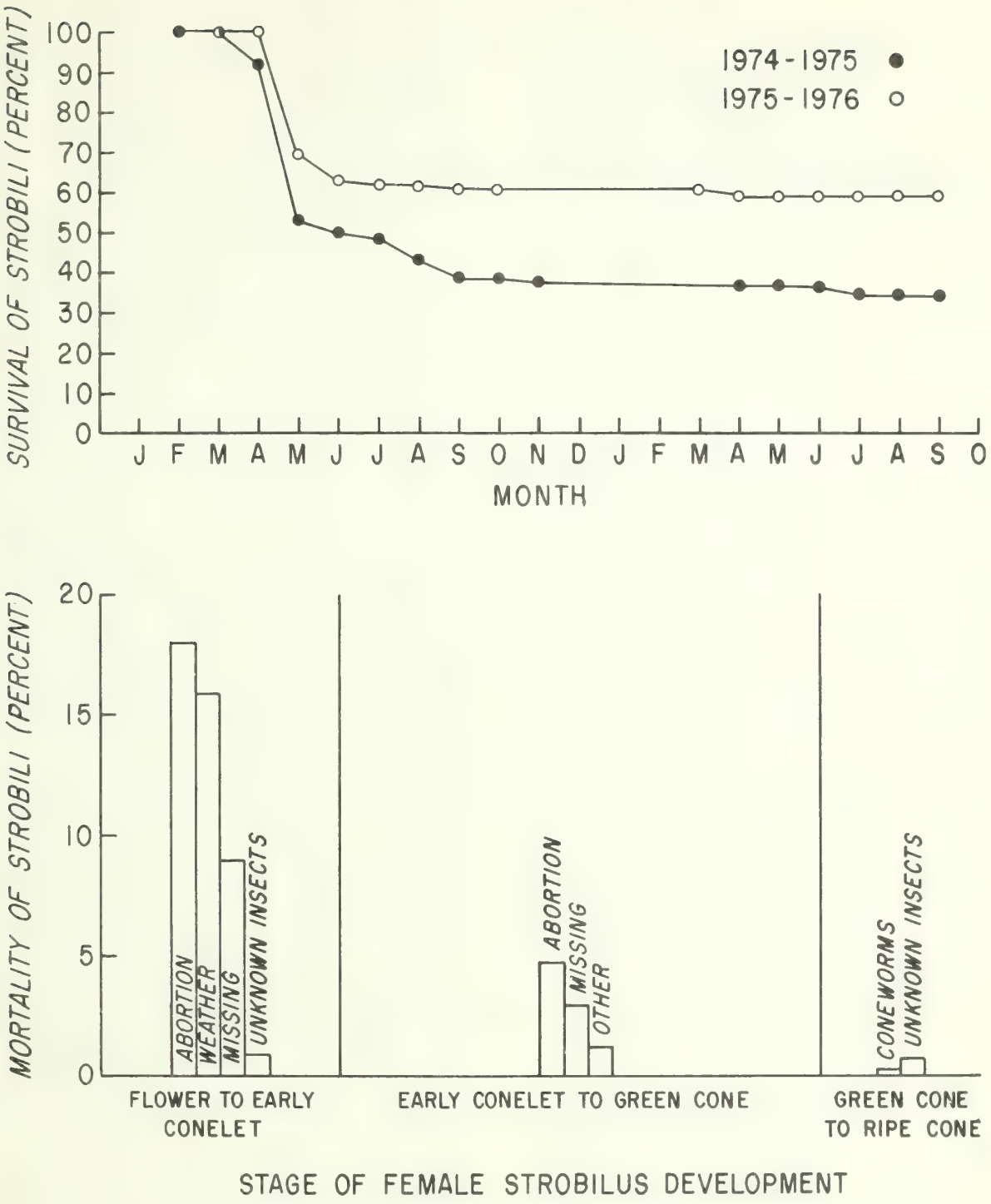

Figure 6.—Survival curves and the average mortality due to different factors for strobili of Virginia pine in the Beech Creek (N.C.) seed orchard from 1974 to 1976.

Late Conelet Stage

The second greatest period of mortality occurred while strobili were in the late conelet stage from about June of the first year through June of the second year of development. During this 12-month period, 3.0 to 59.6 percent of the strobili died. This represented an average of 33.3 percent of the total mortality observed in all of the orchards. Some of the mortality, however, resulted from attacks that were initiated during the flower to early conelet stage such as those by thrips, coneworm shoot attacks, and tip moths.

The late conelet stage represented the period of heaviest mortality of loblolly pine strobili in the Magnolia Springs orchard in 1975 and of longleaf pine strobili in the Stuart orchard during the same year, with most of the mortality occurring between July and September. In the Magnolia Springs orchard, 29.9 percent of the initial flowers died, of which 20.6 percent of the initial strobili aborted or were missing and 4.8 percent were killed by coneworms. The heavy mortality of longleaf conelets in the Stuart orchard (59.6 percent of the initial flowers) was associated with attacks by unknown insects and is similar to that reported by McLemore (1977b) for longleaf pine conelets in the same orchard from June to September of 1973.

In the remainder of the orchards, a large proportion of the late conelet mortality (up to 13.5 percent) was due to conelet abortion and missing conelets. Insects destroyed up to 28.3 percent of the conelets initially present as flowers, of which coneworms were responsible for up to 27.6 percent, unknown insects destroyed up to 15.4 percent, and *Pityophthorus* sp. were found infesting 1.0 to 2.5 percent of the loblolly conelets in the Magnolia Springs orchard.

Green to Ripe Cone Stages

The period of lowest mortality occurred when strobili were in the last stages of development, i.e., from the time the late conelets began rapid elongation during June or July until they were harvested as ripe cones in September or October of the second year of strobilus development. During this 3- to 4-month period, <0.1 to 9.2 percent of the initial strobili were killed as cones which accounted for an average of 7.9 percent of the total mortality observed in all orchards. Up to 7.4 percent of the initial strobili were killed by insects. Within individual orchards, coneworms destroyed up to 7.4 percent of the strobili, unknown insects had attacked up to 1.6 percent of them, up to 1.6 percent were aborted or missing, and up to 1.8 percent were lost to unknown factors.

Counts of harvested cones are frequently used to evaluate damage by coneworms, seedworms, and other insects that attack cones during this period. DeBarr (1974a) found that such counts underestimated the total coneworm damage on slash pine cones by about 40 percent in north Florida. In this study we found that counts of harvested cones both underestimated and overestimated the total damage caused by coneworms (table 15). If the total number of strobili present at a time prior to harvest is known and is used as a basis for calculating percent damage, the damage estimated at harvest will generally underestimate the actual damage between the two times. The degree of underestimation will depend upon the number of strobili damaged by coneworms that fall from the trees before harvest, i.e., those damaged cones not included in the harvest count. The degree of overestimation or underestimation is also dependent on the number of total cones observed at the time the damage estimate is made. The greater the number of strobili missing because of other mortality factors from the observed total number of strobili present at a given time, i.e., those strobili that unaccountably fell from the tree prior to the observation, the greater the degree of overestimation by damage counts for a given factor. This overestimation is also readily apparent from comparison of the q_x and r_x columns in tables 10–14. The two mortality rates are equal at the beginning of each life table, but the rate q_x progressively overestimates the actual mortality rate, r_x, between time intervals in which mortality occurs. The rate q_x, however, indicates the mortality for the strobili remaining on trees at a given time and may be the only estimate available. It is particularly useful for making decisions for insect control as it indicates the current damage level for the insect in question.

Overall Effect of Strobilus Mortality Factors

The Stuart seed orchard is approximately 43.1 hectares in size and contains four species of pines. Ramets of loblolly and shortleaf pines occupy most of the orchard area (44.9 and 43.7 percent, respectively) while ramets of longleaf and slash pines occupy only 7.5 and 3.8 percent of the area, respectively. As all four species of pines were observed during the same period, it can be assumed that mortality factors reported for strobili of one species of pine had approximately

Table 15.—Comparison of damage estimates for coneworms made from counts of strobili throughout their development, during the late conelet stage, and at cone harvest

Pine species and orchard	Flower year	Estimated total strobili ($\hat{Y}$)			Estimated late conelets ($\hat{Y}$) in May or June of second year			Estimated cones at harvest ($\hat{Y}$)		
		Total initial flowers	Total coneworm attacks through harvest[a]		Total late conelets	Total coneworm attacks through harvest[a]		Total harvested cones	Total coneworm attacks on harvested cones[a]	
		..... *No.*		*Percent*	..... *No.*		*Percent*[b]	..... *No.*		*Percent*[b]
Loblolly:										
Hiwassee (Tenn.)	1974	37,940	3,442	9.1	22,306	777	3.5	22,306	777	3.5
	1975	67,349	2,492	3.7	36,254	427	1.2	35,363	0	0
Magnolia Springs (Tex.)	1974	30,764	4,186	13.6	24,099	3,612	15.0A	21,966	1,541	7.0
	1975	58,948	7,233	12.3	34,207	4,344	12.7A	32,273	1,665	5.2
Stuart (La.)	1975	28,098	4,718	16.8	15,835	1,386	8.8	14,508	128	.9
Longleaf:										
Stuart (La.)	1975	3,801	759	20.0	546	172	31.5A	523	149	28.5A
Shortleaf:										
Ouachita (Ark.)	1974	70,310	3,712	5.3	6,789	2,756	40.6A	6,789	106	1.6
	1975	14,713	1,179	8.0	2,936	506	17.2A	2,430	0	0
Stuart (La.)	1975	86,867	376	.4	27,864	78	.3	27,786	0	0
Slash:										
McColsky (Fla.)	1973	60,368	10,186	16.9	40,779	2,178	5.3	38,777	711	1.8
	1974	92,653	18,642	20.1	52,738	12,245	23.2A	47,404	7,620	16.1
	1975	71,654	26,375	36.8	28,568	5,661	19.8	26,848	2,852	10.6
Stuart (La.)	1975	3,987	1,573	39.5	1,333	305	22.9	1,113	30	2.7
Virginia:										
Beech Creek (N.C.)	1974	36,450	181	.5	13,212	181	1.4A	12,492	0	0
	1975	46,993	351	.7	27,864	0	0	27,864	0	0

[a]Attacks include strobili killed and damaged by coneworms.

[b]Percentages followed by the letter A represent overestimates of the total damage caused by coneworms; other percentages overestimated the total coneworm damage.

equal access to the other species of pine in the orchard. If this assumption is made, comparisons of the effect of various mortality factors can be made between pine species.

In the Stuart orchard, strobilus abortion was observed only on longleaf and shortleaf pines, but strobili were found missing between observations on all four pine species. The total percentage for strobili found aborted plus missing was greatest for shortleaf pine (34.4 percent), and least for longleaf pine (5.1 percent), slash pine (7.1 percent), and for loblolly pine (3.4 percent). Among the other orchards surveyed, aborted plus missing strobili were also highest for shortleaf pine (38.2 percent) as well as Virginia pine (34.2 percent) and loblolly pine (29.7 percent), but least for slash pine (14.4 percent).

Coneworms were observed to attack strobili on all four species of pines in this orchard. The percentage of strobili killed by coneworms was lowest for shortleaf pine (0.4 percent), about equal for loblolly pine (16.5 percent) and longleaf pine (16.7 percent), and highest for slash pine (38.7 percent). Comparative values for percentages of strobili killed by coneworms in the other orchards surveyed indicated the same relationship, i.e., average percentages for total strobilus mortality by coneworms in the other orchards were: shortleaf pine, 5.6 percent; loblolly pine, 7.2 percent; and slash pine 19.5 percent. Strobili of Virginia pine were the least affected by coneworms (average mortality = 0.6 percent).

Loopers have been observed to destroy flowers of loblolly, shortleaf, and slash pines (Ebel and others 1975). In the Stuart orchard, however, they were observed to destroy only strobili of loblolly pine. May beetles feed on strobili of loblolly, longleaf, and shortleaf pines (Ebel and others 1975), but were recorded only on loblolly and shortleaf pines in the Stuart orchard. Strobilus mortality attributed to unknown insects, i.e., strobili which exhibited evidence of external feeding by insects, during this same time period was relatively high for longleaf pine (17.3

percent), shortleaf pine (12.5 percent), and slash pine (7.4 percent) in the orchard. Damage by loopers and May beetles is difficult to positively identify when the insects are not present. The behavior of these insects further obscures positive identification as loopers often retreat into foliage when not feeding and May beetles are nocturnal feeders (Ebel and others 1975).

Yates and Ebel (1978) found damage by tip moths to be of minor importance on loblolly pine strobili, which was consistent with diminished shoot attacks by tip moths on loblolly pines greater than 3 meters tall, but reported tip moths to be a major cause of loss for conelets of shortleaf pine. Tip moth damage to strobili in the Stuart orchard was of minor importance on both pine species (loblolly pine, 0.7 percent; shortleaf pine, 1.2 percent). In the other orchards, however, tip moths were not observed on loblolly pine strobili (all ramets were more than 3 meters tall), but were of major importance on shortleaf pine in the Ouachita orchard (16.7 to 44.6 percent mortality) on trees also greater than 3 meters in height. McLemore (1977b) found no evidence of tip moth damage on strobili other than those of shortleaf pine in the Stuart orchard during the 3 years preceding our survey. He also found them to cause minor damage (about 2 percent) to shortleaf pine strobili in this orchard.

Seed Yields from Harvested Cones

A substantial quantity of seeds was not removed from harvested cones by our first extraction method which was selected to closely approximate commercial seed extraction methods. The average amounts of total seed remaining in the five species of extracted cones were: (1) loblolly pine, 44.5 percent (range 29.4 to 68.4 percent); (2) longleaf pine, 26.2 percent; (3) shortleaf pine, 42.6 percent (range 26.6 to 69.9 percent); (4) slash pine, 34.1 percent (range 13.4 to 62.4 percent); and (5) Virginia pine, 37.5 percent (range 9.5 to 65.5 percent) (tables 16–20). This unextracted seed represented an average of 15.9 percent (1.8 to 40.4 percent) of the total viable seed present in the harvested cones.

The majority of seed present in harvested cones was classified as full or sound for all species

Table 16.—Estimated seed yield and coefficient of variation (C.V.) of loblolly pine cones harvested in the Hiwassee (Tenn.), Magnolia Springs (Tex.), and Stuart (La.) seed orchards

Orchard	Flower year	Seed extraction (No.)	No. seed extracted ($\bar{Y}$)	C.V. (%)	Percent of total seed							Average No. seed/cone ($\bar{S}$)
					Full	Empty	Seed-bug damaged	Seed-worm damaged	Malformed	Total	Germinated	
Hiwassee	1974	1	254,234	26.1	21.2	9.3	1.0	0.1	0.0	31.6	18.1	11.4
		2	551,489	14.1	46.8	17.1	2.7	1.9	.1	68.4	35.6	24.7
		Total	805,723	15.9	68.0	26.4	3.6	1.9	.1	100.0	53.8	36.1
Hiwassee	1975	1	1,333,055	13.6	40.2	21.9	3.3	.4	.3	66.1	31.8	37.7
		2	684,815	16.0	16.7	15.1	.1	.9	1.1	33.9	12.6	19.4
		Total	2,017,870	13.8	56.9	37.0	3.4	1.3	1.4	100.0	44.4	57.1
Magnolia Springs	1974	1	1,412,282	14.9	47.6	15.5	6.9	(a)	2	70.3	44.3	66.5
		2	597,897	18.3	16.0	9.6	3.3	.1	.8	29.7	14.5	28.1
		Total	2,010,179	14.5	63.5	25.1	10.2	.1	1.1	100.0	58.8	94.6
Magnolia Springs	1975	1	1,104,940	10.7	38.2	19.2	12.6	(a)	5	70.6	37.6	34.8
		2	459,707	8.3	13.1	11.4	4.2	.2	.5	29.4	12.5	14.5
		Total	1,564,647	8.8	51.3	30.6	16.9	.2	1.0	100.0	50.1	49.3
Stuart	1975	1	358,169	41.9	25.9	12.7	.1	(a)	.3	39.0	24.8	24.0
		2	559,372	12.6	35.6	22.9	1.5	.6	.3	61.0	33.7	40.5
		Total	917,541	23.4	61.4	35.7	1.6	.7	.7	100.0	58.6	64.5

[a] Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

Table 17.—Estimated seed yield and coefficient of variation (C.V.) of longleaf pine cones harvested in the Stuart (La.) seed orchard

Orchard	Flower year	Seed extraction (No.)	No. seed extracted ($\hat{Y}$)	C.V. (%)	Percent of total seed							Average No. seed/ cone ($\bar{S}$)
					Full	Empty	Seed-bug damaged	Seed-worm damaged	Malformed	Total	Germinated	
Stuart	1975	1	18,058	55.2	62.0	8.5	0.3	0.3	2.9	73.8	52.5	34.5
		2	6,405	40.4	4.5	5.5	.2	10.9	5.2	26.2	1.8	12.3
		Total	24,463	49.9	66.5	13.9	.4	11.1	8.0	100.0	54.4	46.8

Computer totals truncated to nearest thousandth.

Table 18.—Estimated seed yield and coefficient of variation (C.V.) of shortleaf pine cones harvested in the Ouachita (Ark.) and Stuart (La.) seed orchards

Orchard	Flower year	Seed extraction (No.)	No. seed extracted (Y)	C.V. (%)	Percent of total seed							Average No. seed/ cone ($\bar{S}$)
					Full	Empty	Seed-bug damaged	Seed-worm damaged	Malformed	Total	Germinated	
Ouachita	1974	1	195,806	19.4	34.0	32.3	1.8	(a)	0.4	68.6	29.2	28.9
		2	89,781	23.2	11.9	17.9	1.4	0	.3	31.4	9.0	13.2
		Total	285,587	18.3	46.0	50.2	3.2	(a)	.7	100.0	38.2	42.1
	1975	1	21,415	24.3	15.7	11.2	2.1	.9	.1	30.1	14.3	9.1
		2	49,801	22.2	18.7	30.2	14.3	5.9	.9	69.9	13.6	21.0
		Total	71,216	20.3	34.4	41.4	16.4	6.8	1.0	100.0	27.9	30.1
Stuart	1975	1	608,418	23.7	10.8	60.7	1.7	0	.2	73.4	10.4	21.9
		2	220,235	21.6	2.4	21.0	3.0	0	.2	26.6	2.3	7.9
		Total	828,653	22.1	13.2	81.7	4.7	0	.3	100.0	12.7	29.8

[a]Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

except shortleaf pine. An average of 64.1 percent of the total extracted seed of loblolly, longleaf, slash, and Virginia pine was full and 55.2 percent of the total seed germinated. However, the average percentage of full seed for shortleaf pine was 31.2 and an average of only 26.3 percent of the total seed germinated.

An average of 32.4 percent (range 13.9 to 81.7 percent) of the seed extracted from the 15 crops of cones surveyed was classified as empty on radiographs and represented the largest loss category. Seed-bug damage was generally the second greatest cause of seed loss recognizable on the radiographs except for seed of longleaf pine. Seed bugs destroyed an average of 7.7 percent (range 0.3 to 19.6 percent) of the loblolly, shortleaf, slash, and Virginia pine seed but accounted for only 0.4 percent of the longleaf pine seed loss. Seedworms destroyed 11.1 percent of the longleaf pine seed, and an additional 8.0 percent of the longleaf pine seed were malformed. Both seedworm damage and the occurrence of malformed seed were of minor importance for the other four species of pine.

The percentage estimates for various categories of seed yields presented in tables 16 to 20 were based on the total numbers of developed seeds present in the harvested cones. These estimates are analogous to those for strobili listed under the q_x columns of the life tables and are primarily useful for determining seed quality at harvest. The estimated seed yields of the initial populations of strobili are given in table 21. These estimates are the product of the above percent-

Table 19.—Estimated seed yield and coefficient of variation (C.V.) of slash pine cones harvested in the McColsky (Fla.) and Stuart (La.) seed orchards

Orchard	Flower year	Seed extraction (No.)	No. seed extracted ($\hat{Y}$)	C.V. (%)	Percent of total seed							Average No. seed/cone ($\bar{S}$)
					Full	Empty	Seed-bug damaged	Seed-worm damaged	Malformed	Total	Germinated	
McColsky	1973	1	1,385,753	15.4	63.0	14.5	8.5	0.2	0.3	86.6	53.0	36.2
		2	215,288	20.2	9.4	2.0	1.7	.4	0	13.4	6.7	5.6
		Total	1,601,041	14.8	72.5	16.5	10.2	.5	.3	100.0	59.7	41.8
	1974	1	2,524,934	12.2	50.6	10.0	5.3	(a)	.1	66.0	48.3	53.8
		2	1,299,603	7.5	24.8	4.5	3.6	1.0	.1	34.0	21.8	27.7
		Total	3,824,537	9.6	75.4	14.5	8.8	1.1	.3	100.0	70.1	81.5
	1975	1	1,285,157	30.0	49.0	12.7	11.6	(a)	.1	73.4	42.5	47.9
		2	464,885	10.2	15.4	2.7	8.0	.4	(a)	26.6	13.6	17.3
		Total	1,750,042	21.9	64.4	15.5	19.6	.4	.1	100.0	56.1	65.2
Stuart	1975	1	18,933	36.3	27.6	9.0	.8	0	.2	37.6	27.3	17.0
		2	31,444	38.0	39.6	19.6	1.2	1.4	.5	62.4	40.4	28.3
		Total	50,377	36.8	67.2	28.6	2.0	1.4	.7	100.0	67.6	45.3

[a]Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

Table 20.—Estimated seed yield and coefficient of variation (C.V.) of Virginia pine cones harvested in the Beech Creek (N.C.) seed orchard

Orchard	Flower year	Seed extraction (No.)	No. seed extracted ($\hat{Y}$)	C.V. (%)	Percent of total seed							Average No. seed/cone ($\bar{S}$)
					Full	Empty	Seed-bug damaged	Seed-worm damaged	Malformed	Total	Germinated	
Beech Creek	1974	1	338,627	18.4	64.5	20.1	5.7	0.1	0.1	90.5	51.8	27.1
		2	35,355	24.9	4.7	2.8	1.7	.2	0	9.5	3.0	2.8
		Total	373,982	17.7	69.2	22.9	7.4	.3	.1	100.0	54.7	29.9
	1975	1	333,205	18.0	20.5	13.6	.1	0	.3	34.5	17.6	12.0
		2	632,510	18.2	32.3	32.5	.2	.5	(a)	65.5	17.0	22.7
		Total	965,715	16.5	52.7	46.2	.3	.5	.3	100.0	34.7	34.7

[a]Less than 0.05 percent.

Computer totals truncated to nearest thousandth.

ages and the proportions of initial strobili that survived to harvest, and therefore include mortality of the strobili. The percentage of seed germinated represents the estimated yield of the population in viable seed and ranged from 3.7 to 40.6 percent among the species of pine surveyed. Average yields for each species of pine were: loblolly pine, 29.7 percent; longleaf pine, 7.5 percent; shortleaf pine, 4.2 percent; slash pine, 37.0 percent; and Virginia pine, 19.5 percent. These values could be used to estimate the expected viable seed yields of a given clone or orchard in the absence of insect control as follows:

$$\hat{SY} = (IF \times SS \times SC \times VY) / 10{,}000$$

where:

$\hat{SY}$ = estimated yield of viable seed

IF = number of initial flowers

SS = percentage of strobilus survival

SC = average number of developed seed/cone at harvest

VY = percentage of viable seed/cone at harvest.

The proportions of seed falling into various other categories, e.g., empty seed, damaged seed, or malformed seed, represent losses in the observed yields of developed seed realized at harvest. The total mortality of developing seed, however, is underestimated by these values.

The total losses of seed in harvested cones would be more accurately estimated with the procedures reported by Bramlett and others (1977), using seed potentials for cones of a given clone or orchard. Estimates resulting from these procedures include losses of aborted ovules which were not included in our survey. The resulting increases in total seed per cone would further decrease our estimates of the percentages of viable seed yields (table 21). The average seed potential in numbers of seed per cone reported by Bramlett (1974a) for southern pines were: loblolly pine, 155; shortleaf pine, 87; Virginia pine, 88; and slash pine, 170. Applying these estimates of seed potentials to the results of our study, the average yields of viable seed for the species of pine surveyed are: loblolly pine, 11.1 percent; shortleaf pine, 1.6 percent; slash pine, 12.0 percent; and Virginia pine, 7.3 percent.

Table 21.—Estimated seed yield of orchards surveyed

Pine species and orchard	Flower year	Survival of initial strobili	Seed collected at harvest				Viable seed yield	
			Avg. total seed/cone ($\bar{S}$)	Avg. potential seed/cone[a]	Avg. filled seed/cone ($\bar{S}$)	Avg. germinated seed/cone ($\bar{S}$)	Avg. of total harvested seed/initial flower[b]	Avg. of potential seed/initial flower[c]
		Percent	..... *No.*				..... *Percent*	
Loblolly								
Hiwassee (Tenn.)	1974	58.8	36.1	155	24.5	19.4	31.6	7.4
	1975	52.5	57.1	155	32.5	25.4	23.3	8.6
Magnolia Springs (Tex.)	1974	69.1	94.6	155	60.1	55.6	40.6	24.8
	1975	53.9	49.3	155	25.3	24.7	27.0	8.6
Stuart (La.)	1975	50.6	64.5	155	39.6	37.8	29.7	12.3
Longleaf								
Stuart (La.)	1975	13.8	46.8	—	31.1	25.4	7.5	—
Shortleaf								
Ouachita (Ark.)	1974	9.7	42.1	87	19.3	16.1	3.7	1.9
	1975	16.1	30.1	87	10.4	8.4	4.5	1.6
Stuart (La.)	1975	32.0	29.8	87	3.9	3.8	4.1	1.4
Slash								
McColsky (Fla.)	1973	63.5	41.8	170	30.3	24.9	37.9	9.3
	1974	50.7	81.5	170	61.4	57.1	35.5	17.0
	1975	37.5	65.2	170	42.0	36.6	21.0	8.1
Stuart (La.)	1975	27.9	45.3	170	30.4	30.6[d]	18.9	5.0
Virginia								
Beech Creek (N.C.)	1974	34.3	29.9	88	20.7	16.4	18.8	6.4
	1975	59.3	34.7	88	18.3	12.0	20.6	8.1

[a] Bramlett (1974b).

[b] Seed yield = germinated seed ÷ total seed × percent strobilus survival.

[c] Seed yield = germinated seed ÷ potential seed × percent strobilus survival = seedling efficiency (Bramlett and others 1977) × percent strobilus survival, assuming extraction efficiency = 100 percent.

[d] Some seed classified as other than full on the radiographs apparently germinated.

CONCLUSIONS

1. In general, more than half (30.9 to 90.3 percent) of the strobili initially present as flowers on loblolly, longleaf, shortleaf, slash, and Virginia pines were lost before cone harvest. The majority of these losses occurred during the spring of the first year of strobilus development. Losses continued to occur throughout development, but the mortality rate decreased with increasing strobilus age. Measures taken to reduce strobilus mortality should be most effective during the spring and summer of the first year of strobilus development.

2. Primary mortality factors for strobili of southern pines were abortion, coneworms, tip moths, loopers, thrips, and unknown insects. Flowers and conelets reported as aborted and missing generally accounted for the greatest loss of Virginia and loblolly pine strobili. The percentage of strobili lost to insects was about equal to that caused by abortion and missing on shortleaf pine, but insects were the primary causes of strobilus mortality on longleaf and slash pines.

3. Both subtle and obvious differences in causes of strobilus mortality and of strobilus loss between pine species, orchard locations, and years were readily discernible from the life table data. These differences demonstrate the need for monitoring the development of strobili in different pine seed orchards to determine and anticipate the need for management practices designed to produce maximum yields of strobili.

4. The majority of the total seed present in harvested cones were viable (55.2 percent). Most of the nonviable seed were empty. Seed-bug damaged seed represented the second largest category of nonviable seed. Seedworms were of minor importance as seed-destroying agents for all species except longleaf pine. Refinement of seed extraction procedures could result in substantial gains in viable seed yields from harvested cones.

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APPENDIX

Estimates of clonal totals of strobili for specified time periods and seed extracted from mature cones for data collected were produced according to the formulas given by Murthy (1967).

The population total for a given clone (Y_i) was estimated by:

$$Y_i = \left(\frac{B_i}{b_i}\right) \sum_{j=1}^{b_i} \left(\frac{N_{ij}}{n_{ij}}\right) \sum_{k=1}^{n_{ij}} Y_{ijk}$$

where:

Y_{ijk} = number of strobili or seed from a cluster

i,j,k = subscripts whose ranges are:

$i = 1, \ldots, A$ (= total number of clones)

$j = 1, \ldots, B_i$ (= total number of ramets in the i^{th} clone)

$k = 1, \ldots, N_{ij}$ (= total number of clusters on the j^{th} ramet in the i^{th} clone)

a, b_i, n_{ij} = sample numbers corresponding to A, B_i, and N_{ij}, respectively.

An estimate of the population total ($\hat{Y}$) was the sum of the clonal estimates:

$$\hat{Y} = \sum_{i=1}^{a} \left(\frac{B_i}{b_i}\right) \sum_{j=1}^{b_i} \left(\frac{N_{ij}}{n_{ij}}\right) \sum_{k=1}^{n_{ij}} Y_{ijk}$$

$$= \sum_{i=1}^{a} Y_i$$

The variance (V) of Y_i was estimated by:

$$V(Y_i) = \frac{B_i^2(1-f_i)}{b_i(b_i-1)} \left(\sum_{j}^{b_i} N_{ij}^2 \bar{y}_{ij}^2 - b_i \bar{y}_i^2\right)$$

$$+ \frac{B_i}{b_i} \sum_{j}^{b_i} \frac{N_{ij}^2(1-f_{ij})}{n_{ij}(n_{ij}-1)} \left(\sum_{k}^{n_{ij}} Y_{ijk}^2 - n_{ij} \bar{y}_{ij}^2\right)$$

where:

$$\bar{y}_{ij} = \frac{1}{n_{ij}} \sum_{k}^{n_{ij}} Y_{ijk}$$

$$f_{ij} = n_{ij}/N_{ij}$$

$$\bar{y}_i = \frac{1}{b_i} \sum_{j}^{b_i} \frac{N_{ij}}{n_{ij}} \sum_{k}^{n_{ij}} Y_{ijk}$$

$$f_i = b_i/B_i$$

The variance (V) of $\hat{Y}$ was estimated as:

$$V(\hat{Y}) = \sum_{i}^{a} V(Y_i)$$

The coefficient of variation (C.V.) of $\hat{Y}$ was estimated by:

$$C.V.(\hat{Y}) = [100(V(\hat{Y}))^{1/2} / \hat{Y}]$$

The average number of seed per cone $\bar{S}$ was estimated by:

$$\bar{S} = [\hat{Y} \text{ (seed)} / \hat{Y} \text{ (harvested cones)}]$$

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Fatzinger, Carl W., Gerard D. Hertel, Edward P. Merkel, William D. Pepper, and R. Scott Cameron.

1980. Identification and sequential occurrence of mortality factors affecting seed yields of southern pine seed orchards. USDA For. Serv., Res. Pap. SE-216, 43 p. Southeast. For. Exp. Stn., Asheville, N.C.

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KEYWORDS: *Pinus taeda*, *P. elliottii*, *P. echinata*, *P. palustris*, *P. virginiana*, cone and seed insects, life tables, insect impact.

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Prediction of Growth after Thinning in Old-Field Slash Pine Plantations

by

Jerome L. Clutter
and
Earle P. Jones, Jr.

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August 1980

Southeastern Forest Experiment Station
Asheville, North Carolina

Prediction of Growth after Thinning in Old-Field Slash Pine Plantations

by
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ABSTRACT.—An algorithm is given for projecting stand structure in old-field slash pine plantations from current stand statistics that represent conditions after thinning from below, or without thinning. The algorithm is based on data collected from 212 quarter-acre plots in slash pine's range in Georgia, Florida, Alabama, and Mississippi. Plots represented ages from 9 to 32 years, basal areas from 25 to 150 square feet, and site indexes (at base age 25) of 47 to 80 feet. Projections for selected combinations of age, site index, and density are evaluated for total cubic-foot and board-foot volume production after thinning of 20, 25, 33, and 50 percent of volume and without thinning.

Keywords: *Pinus elliottii*, yield, mensuration.

Foresters have long recognized the mensurational and economic complexities involved in analyzing the effects of thinning. Valuable data on responses of thinned southern pine stands can be found in the reports of case histories and locally replicated studies (e.g., Dell and Collicott 1968; Keister, Crow and Burns 1968; Enghardt and Mann 1972), but no results from regional studies have been published.

This report presents initial results from a cooperative regional thinning study organized by the Southeastern Forest Experiment Station. Results include:

- A series of mathematical equations for predicting the subsequent development of thinned (or unthinned) old-field slash pine plantations.
- A comparison of predicted growth with actual growth for the plots that were used to develop the prediction equations.
- An analysis of the effects of thinning under a wide variety of situations.

A FORTRAN subroutine for computer implementation of the prediction equations is given in the Appendix.

THE DATA BASE

In 1958, the Southeastern Forest Experiment Station and a number of cooperators began a large slash pine plantation density study. The principal objective was to determine the effects of different residual stand densities upon the cubic-foot volume growth and total yield of planted slash pine over a broad range of ages and sites. Eighteen industry, government, and nonindustrial private landowners cooperated in providing old-field slash pine plantations for sampling. Sample plots were widely scattered over the Coastal Plain of southern Georgia and northern Florida, and along the Gulf Coast of Alabama and Mississippi. Slash pine plantations were selected for sampling to provide a broad representation of plantation ages and site indexes (based on a 25-year index age). Residual stand densities were in 25-square-foot basal-area classes with midpoints of 40, 65, 90, 115, 140, and 165.[1] Plantations were not chosen if they had a history of naval stores operations, frequent or damaging fires, or heavy rust infection; nor were those that had been interplanted or thinned. Plots were placed in portions of the plantation that had rather uniform planted pine stocking. No more than six merchantable-

[1]Ages at the beginning of the growth period ranged from 9 to 32 years. Minimum and maximum site-index values (calculated using Equation 3 in table 1) were 47 feet and 80 feet, respectively. Basal areas at the beginning of the growth period varied from 25 square feet per acre to 150 square feet per acre.

size wild pines or hardwoods were allowed. Greater numbers of unmerchantable wildlings were permitted.

In all, 296 monumented plots were established. Most were four-sided, as nearly square as plantation row alignment would allow, and close to one-quarter acre in size. Also included were some circular quarter-acre plots which were part of a similar study started in 1955.

The number of sample plots installed in each selected plantation depended on the highest density available. Except for those with a uniquely high basal area, plots in a plantation were randomly assigned for thinning to a basal-area class. Thinnings reduced basal area as nearly as practicable to the midpoint of the density class; plots with existing basal areas near the midpoint of their assigned class were left unthinned. Thinnings generally consisted of improvement cuts from below. Thus, most cut trees were in the lower merchantable and submerchantable diameter classes, but larger trees were taken if they were badly diseased or deformed. Due regard was given to the spacing of residuals to avoid "holes" in the residual stand.

Initial plot measurements included a 100-percent diameter tally of pine and hardwood trees more than 6 feet tall and a classification as to sawtimber or pulpwood. In each diameter class, the first and every following eighth tree were designated for measurements of total height, height to green crown, and crown class. Trees with a broken top, a low fork, or some other deformity that obviously affected height were passed over, and the next acceptable tree in the diameter class was measured.

The plots were remeasured in a similar way at the end of the growth period 5 years later. Trees in the original height sample were remeasured, and additional trees were measured to give at least the one-in-eight sample according to the new diameter distribution. Thinning treatments and remeasurements have continued beyond the first growth period, but the results are not reported here.

First and second measurements were compared for each plot and tree. Obvious errors were corrected, but plots for which data could not be reconciled were left out of the growth analysis. Of the original 296 plots installed, 212 were used in the present analysis.

THE STAND-STRUCTURE PROJECTION ALGORITHM

Analysis of the data base just described has produced a computerized algorithm for predicting the future stand structure of old-field slash pine plantations. To make predictions, the following information about the residual stand is necessary:

- Age of the stand.
- Site index (25-year index age).
- A current stand table that shows the number of trees per acre by 1-inch diameter class together with the average diameter and average height of the trees in each class.

Diameter distributions after thinning may be measured or they may be calculated by the method of Bennett and Clutter (1968) and Bennett (1970). When diameter distributions are calculated, diameter class midpoints will generally serve as the initial average diameters. When the stand table is based on field measurements, the average diameters can be calculated as mean d.b.h. values by diameter class.

The equations for the stand-structure projection algorithm are listed below:

$$N_2 = [N_1^{-0.870841} + 0.0000146437\,(A_2^{1.37454} - A_1^{1.37454})]^{[(-0.870841)^{-1}]} \quad (1)$$

$$\ln(B_2) = (A_1/A_2)^{0.659976}\ln(B_1) + 5.74478[1 - (A_1/A_2)^{0.659976}] \quad (2)$$

$$\ln(S) = 3.75044 + 1.4488e^{-9.26795/A}[\ln(H) + 17.6098/A - 4.45483] \quad (3)$$

$$\ln(H) = 0.69024e^{9.26795/A}[\ln(S) - 3.75044] - 17.60980/A + 4.45483 \quad (4)$$

$$n_{2i} = [n_{1i}p_i/(\sum_i n_{1i}p_i)]N_2 \quad (5)$$

where $\text{probit}(p_i) = 6.76748 + 1.00456\ln(b_{1i}/\bar{b}_1)$ (*see* footnote 2)

$$d_{2i} = [\bar{b}_2 K(b_{1i}/\bar{b}_1)^U / 0.005454]^{0.5} \quad (6)$$

where $K = N_2 / \sum_i n_{2i}(b_{1i}/\bar{b}_1)^U$

and $U = (A_1/A_2)^{0.0578109}$

$$h_{2i} = H_2(h_{1i}/H_1)^{[(A_1/A_2)^{-0.224491}]} \quad (7)$$

Definitions for symbols in the equations are:

A_1 = plantation age at the beginning of the growth period (years)
A_2 = plantation age at the end of the growth period (years)
N_1 = number of surviving stems per acre at the beginning of the growth period
N_2 = number of surviving stems per acre at the end of the growth period
B_1 = basal area per acre at the beginning of the growth period (square feet)
B_2 = basal area per acre at the end of the growth period (square feet)
H_1 = average height of dominant and codominant trees at the beginning of the growth period (feet)
H_2 = average height of dominant and codominant trees at the end of the growth period (feet)
S = site index at index age of 25 years (feet)
n_{1i} = number of surviving stems per acre in diameter class "i" at the beginning of the growth period
n_{2i} = number of surviving stems per acre in diameter class "i" at the end of the growth period
b_{1i} = average basal area per tree for diameter class "i" at the beginning of the growth period (square feet)
$\bar{b}_1$ = average basal area per tree for the entire stand at the beginning of the growth period (square feet)
d_{1i} = average d.b.h. for diameter class "i" at the beginning of the growth period (inches)
d_{2i} = average d.b.h. for diameter class "i" at the end of the growth period (inches)
$\bar{b}_2$ = average basal area per tree for the entire stand at the end of the growth period (square feet)
h_{1i} = average height of trees in diameter class "i" at the beginning of the growth period (feet)
h_{2i} = average height of trees in diameter class "i" at the end of the growth period (feet)
e = 2.71828 . . ., the base of natural logarithms
ln denotes a natural logarithm
$\sum_i$ denotes a summation over all occupied diameter classes

The following operations are required to apply the equations:

1. Determine the appropriate values for A_1, A_2, N_1, B_1, H_1, and S. N_1 and B_1 can be calculated from the after-thinning stand table. If H_1 is known, S can be calculated from equation (3). If S is known, H_1 can be calculated by solving equation (4) with $A = A_1$.

2. Compute $\bar{b}_1 = B_1/N_1$ and the b_{1i} values.

3. Calculate N_2 and B_2 with equations (1) and (2), and compute $\bar{b}_2 = B_2/N_2$.

4. Compute H_2 by solving equation (4) with $A = A_2$.

5. Calculate the p_i value for each diameter class, and then solve equation (5) for each diameter class to give the n_{2i} values.

6. Solve equations (6) and (7) for each diameter class to give the d_{2i} and h_{2i} values.

These computations produce a stand table showing numbers of trees, average diameters, and average heights by diameter classes at the end of the projection period. The total number of trees per acre in the stand table will be N_2 as calculated from equation (1) in step 3. If basal area per acre is computed from n_{2i} and d_{2i} values, the result will be B_2 as calculated with equation (2) in step 3.

This projection algorithm differs from conventional stand table projection methods in that it does not move trees from one class to another. Instead, the class statistics change. For example, diameter class i begins the growth period containing n_{1i} trees, which are treated as all having

---

[2]The probit transformation is defined as follows:

$$\text{Probit}(x) = 5.0 + Z_x \qquad (0 < x < 1)$$

where Z_x is the value of the standard normal variable such that probability $(Z \leq Z_x) = x$.

d.b.h. values equal to d_{1i} and total heights equal to h_{1i}. At the end of the growth period, n_{2i} of the original n_{1i} trees are still alive with d.b.h. values equal to d_{2i} and total heights equal to h_{2i}. This overall projection procedure is similar to the method developed by Clutter and Allison (1974) for *Pinus radiata* in New Zealand.

A COMPARISON OF OBSERVED AND PREDICTED VALUES

Data from the same 212 growth-period observations that were used to develop the prediction equations were analyzed with the stand structure projection algorithm to generate comparisons of observed growth statistics with corresponding predicted values. On each plot, the observed after-thinning diameter distribution and average heights, by d.b.h. class, were used as input to the algorithm. Predicted end-of-period statistics calculated by the algorithm were compared with corresponding end-of-period observed values.

A summary of these comparisons is shown in table 1. For each stand variable, the average of the observed values and the average of the values predicted by the model are shown together with

Table 1.—Comparison of observed and predicted values, per acre

Stand characteristic	Average observed value	Average predicted value	Percent of variation explained
ALL PLOTS (n = 212)			
Number of trees at age A_2	298.6	299.5	98.7
Basal area at age A_2 (ft^2)	100.4	100.5	96.7
Cubic-foot volume at age A_2	2,598	2,620	93.6
Board-foot volume at age A_2	1,010	1,031	94.0
Mortality during period (number of stems)	18.7	19.6	42.1
Basal-area growth during period (ft^2)	19.6	19.7	59.9
Cubic-foot growth during period	1,000	1,022	81.5
Board-foot growth during period	589	610	85.8
THINNED PLOTS (n = 153)			
Number of trees at age A_2	271.4	274.1*	98.8
Basal area at age A_2 (ft^2)	91.9	92.5	96.5
Cubic-foot volume at age A_2	2,359	2,398	93.0
Board-foot volume at age A_2	822	844	92.3
Mortality during period (number of stems)	17.9	20.7*	54.0
Basal-area growth during period (ft^2)	19.2	19.8	60.8
Cubic-foot growth during period	919	957	65.1
Board-foot growth during period	472	494	73.8
UNTHINNED PLOTS (n = 59)			
Number of trees at age A_2	369.2	365.2	98.0
Basal area at age A_2 (ft^2)	122.6	121.3	93.7
Cubic-foot volume at age A_2	3,217	3,195	91.6
Board-foot volume at age A_2	1,497	1,515	95.1
Mortality during period (number of stems)	20.7	16.7	17.6
Basal-area growth during period (ft^2)	20.8	19.4	56.9
Cubic-foot growth during period	1,210	1,188	90.3
Board-foot growth during period	894	912	91.7

All cubic-foot volume and growth figures are outside-bark merchantable volumes to a 4.0-inch (o.b.) top diameter and include all stems with d.b.h. greater than 4.5 inches. The volume table used was developed by Bennett and others (1959).

All board-foot volume and growth figures are International ¼-inch scale and are based on a volume equation developed by Bennett (1959).

*Average predicted value differs significantly at the 5-percent level from the corresponding average observed value.

the percent of variation explained by the model. For a given stand variable Y, the percent of variation explained was calculated as:

$$PVE = 100\left\{1 - [\Sigma(Y_i - \hat{Y}_i)^2] / [\Sigma(Y_i - \bar{Y})^2]\right\}$$

where:

PVE = percent of variation explained,

Y_i = observed value of Y for observation i,

$\hat{Y}_i$ = predicted value of Y for observation i,

$\bar{Y}$ = $\Sigma Y_i/n$, and

the summations are made over the n observations involved.

These statistics are tabulated for all 212 plots, and for the 153 thinned plots and the 59 unthinned plots. Agreement between observed and predicted values is generally quite close. In two of the 24 comparisons that are tabulated, average observed values differ significantly from the average predicted values. However, in neither of these cases is the magnitude of the difference sufficiently large to be of practical concern. The percentages of variation explained by the projection equations indicate good performance in most prediction situations.

As is common, mortality is predicted with less precision than any of the other dependent variables considered. For the unthinned plots, only 17.6 percent of the variation in observed mortality is explained by the model. Because the comparable figure is 54.0 percent in thinned stands, much of the unexplained mortality variation in unthinned stands is probably occurring in trees that would have been removed if a thinning had been performed (i.e., small trees and diseased trees). The fact that the model explains 90.3 percent of the variation in cubic-foot growth variability while accounting for only 17.6 percent of the variation in mortality seems to confirm this conjecture.

EFFECTS OF THINNING

Calculations were performed to evaluate the effect of thinning on cubic-foot and board-foot production in a large number of representative thinning situations. Evaluations were carried out for various combinations of site index, thinning age, rotation age, stems per acre before thinning, and thinning intensity expressed as a percentage of merchantable cubic-foot volume removed. For each combination, stand structure at thinning age was calculated using techniques described by Bennett (1970) and Burkhart (1971). Yield without thinning was estimated with the stand structure projection algorithm to project this stand structure forward to rotation age. Comparable yield with thinning was obtained by removing sufficient stems from the diameter distribution at the age of thinning (beginning with the 5-inch class and moving upward) to provide the required percentage of volume removal. Projection of this residual stand to rotation age provided a yield estimate for the thinned stand at maturity, and a combination of this figure with the thinning yield gave an estimate of the total yield with thinning. The results of these computations are summarized in table 2.

Table 2 shows that thinning decreased cubic-foot volume production over the entire rotation in all of the cases considered, but the percentage of reduction was relatively small in many instances. Thinning generally increased board-foot volume production over the life of the stand and, in many cases, the percentage of increase was quite large.

Identification of situations where thinning is or is not advantageous requires economic analysis which is not attempted here. A growth-projection algorithm such as we present is required for such analysis, however. Because the algorithm that is presented here can be used for such purposes, a FORTRAN computer subroutine and related instructions for implementing the algorithm are given in the Appendix.

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APPENDIX

Computer Subroutine to Implement the Stand-Structure Projection Algorithm

The computer listing shown in this Appendix is a FORTRAN subroutine designed to carry out the computations in the algorithm that is presented in the text. Arguments that are provided to the subroutine are:

A1 = age of the stand at the beginning of the projection period.

A2 = age of the stand at the end of the projection period.

BA1 = basal area per acre at the beginning of the projection period.

SPA1 = number of stems per acre at the beginning of the projection period.

SI = site index (index age of 25 years).

F = a 20-element array containing initial numbers of stems per acre by d.b.h. classes, where F(I) is the initial number of stems per acre in diameter class I (I = 1, 2, . . ., 20).

D = a 20-element array containing initial average (midpoint) diameters by d.b.h. classes, where D(I) is the initial average diameter in diameter class I (I = 1, 2, . . ., 20).

H = a 20-element array containing initial average heights by d.b.h. classes, where H(I) is the initial average height for diameter class I (I = 1, 2, . . ., 20).

DL = a 20-element array containing initial lower limits for the d.b.h. classes, where DL(I) is the initial lower class limit for diameter class I (I = 1, 2, . . ., 20).

DU = a 20-element array containing initial upper limits for the d.b.h. classes, where DU(I) is the initial upper class limit for diameter class I (I = 1, 2, . . ., 20).

When the subroutine returns to the calling program, F, D, H, DL, and DU will contain values as of the end of the projection period. Other values returned are:

CFV = the per acre cubic-foot volume to a 4.0-inch top (o.b.) for all trees with d.b.h. 4.5 inches and larger.

BFV = the per acre board-foot volume (International ¼-inch scale) to a 6.0-inch top (o.b.) for all trees with d.b.h. 9.5 inches and larger.

This subroutine has been tested on IBM 370/158 equipment with a System/370 FORTRAN IV compiler. The subroutine makes use of the mathematical error function[3] (ERF), which is a FORTRAN-supplied procedure with System/370 FORTRAN. Users wishing to implement the subroutine with a FORTRAN compiler that lacks the ERF function will have to include their own function subprograms to evaluate the error function.

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[3]The error function (ERF) is defined as

$$ERF(x) = (2/\sqrt{\pi}) \int_0^x e^{-u^2} du$$

TABLE 2. -PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING

SITE INDEX: 50 THINNING AGE: 15 ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	278	20	142	0	1952	601	2168	473	-10.0	27.0
400	261	25	177	0	1902	619	2168	473	-12.3	30.8
400	234	33	236	0	1815	652	2168	473	-16.3	37.9
400	179	50	354	0	1619	1848	2168	473	-25.3	290.7
500	367	20	140	0	1934	177	2154	158	-10.7	11.8
500	345	25	175	0	1869	205	2154	158	-13.2	29.2
500	319	33	234	0	1781	214	2154	158	-17.3	35.2
500	267	50	351	0	1581	1022	2154	158	-26.6	545.0
600	474	20	139	0	1900	56	2132	51	-10.9	10.1
600	443	25	174	0	1836	57	2132	51	-13.8	13.3
600	405	33	232	0	1739	67	2132	51	-18.4	32.9
600	358	50	348	0	1539	74	2132	51	-27.8	45.9
700	586	20	139	0	1890	20	2113	19	-11.0	6.8
700	550	25	173	0	1816	21	2113	19	-14.1	11.5
700	502	33	231	0	1706	22	2113	19	-19.3	16.6
700	453	50	347	0	1505	27	2113	19	-28.8	41.9
800	684	20	140	0	1872	11	2107	10	-11.2	7.8
800	655	25	175	0	1807	11	2107	10	-14.2	10.2
800	607	33	233	0	1695	11	2107	10	-19.6	14.7
800	550	50	349	0	1485	14	2107	10	-29.5	38.7

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 50 THINNING AGE: 15 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	278	20	142	0	2539	3530	2822	2620	-10.0	34.7
400	261	25	177	0	2472	3695	2822	2620	-12.4	41.1
400	264	33	236	0	2354	3942	2822	2620	-16.6	50.5
400	179	50	354	0	2085	5023	2822	2620	-26.1	91.7
500	367	20	140	0	2491	2311	2795	1755	-10.9	31.7
500	345	25	175	0	2416	2507	2795	1755	-13.5	42.9
500	319	33	234	0	2295	2686	2795	1755	-17.9	53.1
500	267	50	351	0	2017	3401	2795	1755	-27.8	93.9
600	474	20	139	0	2447	1627	2757	1266	-11.2	28.5
600	443	25	174	0	2361	1756	2757	1266	-14.4	38.7
600	409	33	232	0	2227	1928	2757	1266	-19.2	52.3
600	358	50	348	0	1946	2414	2757	1266	-29.4	90.7
700	580	20	139	0	2411	1243	2726	991	-11.5	25.3
700	550	25	173	0	2324	1329	2726	991	-14.7	34.1
700	502	33	231	0	2171	1482	2726	991	-20.4	49.5
700	453	50	347	0	1889	1636	2726	991	-30.7	65.0
800	684	20	140	0	2390	1028	2709	838	-11.8	22.6
800	655	25	175	0	2302	1091	2709	838	-15.0	30.1
800	607	33	233	0	2145	1216	2709	838	-20.8	45.1
800	550	50	349	0	1851	1337	2709	838	-31.7	59.5

Continued

TABLE 2 PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING CONTINUED

SITE INDEX 50 THINNING AGE 20 ROTATION AGE 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	266	20	274	0	1993	381	2091	349	-4.7	9.2
400	242	25	343	0	1968	390	2091	349	-5.9	11.6
400	211	33	457	0	1927	409	2091	349	-7.9	17.2
400	160	50	686	0	1835	439	2091	349	-12.2	25.8
500	349	20	283	0	2058	102	2162	97	-4.8	5.1
500	324	25	354	0	2033	104	2162	97	-6.0	7.2
500	283	33	472	0	1988	107	2162	97	-8.0	10.7
500	224	50	709	0	1892	122	2162	97	-12.5	25.6
600	433	20	290	0	2101	16	2211	15	-5.0	2.2
600	408	25	362	0	2075	16	2211	15	-6.2	4.4
600	368	33	483	0	2029	17	2211	15	-8.2	8.5
600	294	50	724	0	1927	19	2211	15	-12.8	21.4
700	520	20	295	0	2134	1	2250	1	-5.1	0.1
700	495	25	369	0	2107	1	2250	1	-6.4	2.4
700	455	33	491	0	2059	1	2250	1	-8.5	7.0
700	375	50	737	0	1953	1	2250	1	-13.2	20.2
800	619	20	300	0	2164	0	2283	0	-5.2	0.0
800	585	25	374	0	2134	0	2283	0	-6.5	0.0
800	545	33	499	0	2085	0	2283	0	-8.7	0.0
800	466	50	749	0	1975	0	2283	0	-13.5	0.0

Continued

TABLE 2.- PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING--CONTINUED

SITE INDEX: 50 THINNING AGE: 20 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING REMOVED IN THINNING CU. FT.	YIELD WITH THINNING REMOVED IN THINNING BD. FT.	YIELD WITH THINNING TOTAL YIELD CU. FT.	YIELD WITH THINNING TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	266	20	274	0	2575	2154	2743	1858	-6.1	15.9
400	242	25	343	0	2532	2247	2743	1858	-7.7	21.0
400	211	33	457	0	2458	2443	2743	1858	-10.4	31.5
400	160	50	686	0	2293	2994	2743	1858	-16.4	61.1
500	349	20	283	0	2648	1299	2827	1151	-6.3	12.8
500	324	25	354	0	2604	1358	2827	1151	-7.9	18.0
500	283	33	472	0	2525	1471	2827	1151	-10.7	27.7
500	224	50	709	0	2351	1847	2827	1151	-16.8	60.4
600	433	20	290	0	2695	817	2885	750	-6.6	9.0
600	408	25	362	0	2648	856	2885	750	-8.2	14.2
600	368	33	483	0	2566	933	2885	750	-11.1	24.4
600	294	50	724	0	2381	1166	2885	750	-17.5	55.5
700	520	20	295	0	2727	551	2929	521	-6.9	5.7
700	495	25	369	0	2679	577	2929	521	-8.5	10.7
700	455	33	491	0	2593	630	2929	521	-11.5	20.8
700	375	50	737	0	2399	782	2929	521	-18.1	50.1
800	619	20	300	0	2757	399	2967	381	-7.1	4.7
800	585	25	374	0	2703	411	2967	381	-8.9	8.1
800	545	33	499	0	2615	448	2967	381	-11.9	17.7
800	466	50	749	0	2414	553	2967	381	-18.6	45.3

Continued

TABLE 2 PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING CONTINUED

SITE INDEX: 60 THINNING AGE: 15 ROTATION AGE: 25

TREES/ACRE BEFORE THINNING	TREES/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	264	20	261	0	2952	3037	3169	2551	-6.8	19.0
400	239	25	327	0	2896	3171	3169	2551	-8.6	24.3
400	200	33	436	0	2798	3344	3169	2551	-11.7	31.1
400	155	50	653	0	2579	4135	3169	2551	-18.6	62.1
500	344	20	274	0	3062	2062	3293	1661	-7.0	24.1
500	318	25	343	0	3003	2121	3293	1661	-8.8	27.7
500	277	33	457	0	2899	2246	3293	1661	-12.0	35.2
500	215	50	685	0	2667	2809	3293	1661	-19.0	69.1
600	423	20	285	0	3150	1403	3395	1152	-7.2	21.8
600	400	25	357	0	3088	1491	3395	1152	-9.0	29.4
600	358	33	476	0	2979	1583	3395	1152	-12.3	37.4
600	280	50	713	0	2731	1780	3395	1152	-19.6	54.5
700	509	20	296	0	3229	1027	3490	866	-7.5	18.6
700	484	25	370	0	3165	1091	3490	866	-9.3	25.9
700	441	33	494	0	3050	1202	3490	866	-12.6	38.8
700	356	50	740	0	2788	1340	3490	866	-20.1	54.7
800	602	20	308	0	3312	822	3586	707	-7.7	16.2
800	576	25	384	0	3242	868	3586	707	-9.6	22.7
800	527	33	513	0	3123	963	3586	707	-12.9	36.2
800	442	50	769	0	2850	1088	3586	707	-20.5	53.8

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 60 THINNING AGE: 15 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	284	30	261	0	3680	7303	3549	5887	-6.6	24.0
400	239	75	327	0	3608	7776	3949	5887	-6.6	32.1
400	206	33	436	0	3441	8233	3949	5887	-11.8	39.8
400	155	50	653	0	3192	8207	3949	5887	-19.2	39.4
500	344	20	274	0	3795	5701	4034	4604	-7.1	23.8
500	318	25	343	0	3720	6063	4084	4604	-8.9	31.7
500	277	33	457	0	3555	6788	4084	4604	-12.2	47.5
500	215	50	685	0	3276	7610	4084	4604	-19.8	65.3
600	425	20	235	0	3884	4804	4194	3762	-7.4	22.4
600	400	25	257	0	3804	4904	4194	3762	-9.3	30.4
600	356	33	476	0	3662	5499	4194	3762	-12.7	46.2
600	296	50	713	0	3331	6825	4194	3762	-20.6	81.4
700	509	20	296	0	3963	3893	4294	3239	-7.7	20.2
700	434	25	370	0	3879	4149	4294	3239	-9.7	28.1
700	471	33	494	0	3729	4657	4294	3239	-13.2	43.8
700	356	50	740	0	3375	6136	4294	3239	-21.3	89.5
800	602	20	308	0	4047	3466	4397	2932	-8.0	18.2
800	570	25	364	0	3956	3631	4397	2932	-10.0	23.8
800	527	33	513	0	3798	4127	4397	2932	-13.6	40.7
800	442	50	769	0	3430	5410	4397	2932	-22.0	84.5

Continued

TABLE 3. PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING. CONTINUED

SITE INDEX 60 THINNING AGE 20 ROTATION AGE 25

TREES/ACRE BEFORE THINNING	TREES/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	255	20	458	0	3097	2400	3200	2167	-3.2	10.8
400	234	25	573	0	3070	2461	3200	2167	-4.1	13.6
400	198	33	763	0	3022	2572	3200	2167	-5.6	18.7
400	142	50	1145	0	2914	2871	3200	2167	-8.9	32.5
500	323	20	493	0	3314	1458	3422	1370	-3.2	6.4
500	297	25	616	0	3286	1490	3422	1370	-4.0	8.8
500	251	33	821	0	3237	1552	3422	1370	-5.4	13.3
500	180	50	1232	0	3124	1694	3422	1370	-8.7	23.7
600	404	20	522	0	3499	902	3611	884	-3.1	2.0
600	368	25	653	0	3470	908	3611	884	-3.9	2.7
600	314	33	870	0	3419	938	3611	884	-5.3	6.2
600	246	50	1305	0	3300	1029	3611	884	-8.6	16.4
700	487	20	549	0	3665	588	3782	597	-3.1	-1.6
700	450	25	686	0	3635	590	3782	597	-3.9	-1.2
700	390	33	914	0	3581	593	3782	597	-5.3	-0.6
700	311	50	1371	0	3456	665	3782	597	-8.6	11.3
800	571	20	573	0	3818	405	3941	423	-3.1	-4.4
800	533	25	716	0	3787	407	3941	423	-3.9	-3.9
800	470	33	955	0	3731	409	3941	423	-5.3	-3.3
800	379	50	1433	0	3600	455	3941	423	-8.6	7.6

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 60 THINNING AGE: 20 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	255	20	458	0	3825	6043	3991	5359	-4.2	12.8
400	234	25	573	0	3780	6256	3991	5359	-5.3	16.7
400	196	33	763	0	3700	6663	3991	5359	-7.3	24.3
400	143	50	1145	0	3510	6572	3991	5359	-12.1	22.6
500	329	20	493	0	4069	4579	4242	2760	-4.1	65.9
500	297	25	616	0	4022	4741	4242	2760	-5.2	71.8
500	260	33	821	0	3938	5063	4242	2760	-7.2	83.5
500	188	50	1232	0	3742	5718	4242	2760	-11.8	107.2
600	404	20	522	0	4275	3522	4457	3295	-4.1	6.9
600	368	25	653	0	4227	3613	4457	3295	-5.2	9.7
600	324	33	870	0	4139	3852	4457	3295	-7.1	16.9
600	246	50	1305	0	3933	4562	4457	3295	-11.8	38.5
700	487	20	549	0	4459	1345	4649	2708	-4.1	-50.3
700	450	25	686	0	4408	1369	4649	2708	-5.2	-49.5
700	390	33	914	0	4316	2999	4649	2708	-7.2	10.8
700	311	50	1371	0	4099	3630	4649	2708	-11.8	34.1
800	571	20	573	0	4627	947	4828	2315	-4.2	-59.1
800	533	25	716	0	4574	963	4828	2315	-5.3	-58.4
800	470	33	955	0	4478	994	4828	2315	-7.3	-57.1
800	379	50	1433	0	4250	2994	4828	2315	-12.0	29.3

Continued

TABLE 2. PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING CONTINUED

SITE INDEX: 70 THINNING AGE 15 ROTATION AGE 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED IN THINNING	YIELD WITH THINNING: CU. FT. IN THINNING	YIELD WITH THINNING: BD. FT. IN THINNING	YIELD WITH THINNING: TOTAL CU. FT.	YIELD WITH THINNING: TOTAL BD. FT.	YIELD WITHOUT THINNING: CU. FT.	YIELD WITHOUT THINNING: BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	264	20	414	0	4057	6615	4267	5671	-4.9	21.9
400	234	25	516	0	4086	7203	4267	5671	-6.3	29.6
400	200	33	696	0	4096	7791	4267	5671	-8.7	37.8
400	141	50	1054	0	3954	8810	4267	5671	-14.4	41.8
500	326	20	516	0	4051	5487	4540	4868	-4.5	21.0
500	294	25	645	0	4261	5982	4540	4368	-6.1	21.6
500	251	33	870	0	4153	6158	4540	4368	-8.5	41.0
500	197	50	1315	0	4021	7216	4540	4368	-14.1	67.5
600	401	20	477	0	4515	4159	4783	3494	-4.4	19.9
600	370	25	596	0	4483	4374	4783	3494	-6.1	25.2
600	313	33	774	0	4350	4814	4783	3494	-8.4	37.8
600	245	50	1173	0	4115	6002	4783	3494	-14.0	71.8
700	435	20	558	0	4772	3401	5011	2929	-4.8	16.1
700	445	25	692	0	4707	3577	5011	2929	-6.1	22.1
700	389	33	894	0	4590	3617	5011	2929	-8.4	23.7
700	306	50	1356	0	4310	5010	5011	2929	-14.0	71.0
800	507	20	638	0	4894	2919	5234	2580	-4.8	13.1
800	556	25	870	0	4916	3067	5234	2580	-6.1	18.9
800	489	33	1122	0	4793	3356	5234	2580	-8.4	30.1
800	372	50	1716	0	4498	4278	5234	2580	-14.1	65.8

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 70 THINNING AGE: 15 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	254	20	412	0	4899	12289	5149	9528	-4.8	29.0
400	234	25	515	0	4827	12501	5149	9528	-6.2	31.2
400	200	33	686	0	4698	12726	5149	9528	-8.8	33.6
400	141	50	1029	0	4398	12099	5149	9528	-14.8	27.0
500	326	20	446	0	5185	8919	5444	7376	-4.8	20.9
500	294	25	558	0	5112	9216	5444	7376	-6.1	24.9
500	258	33	743	0	4976	11509	5444	7376	-8.6	56.0
500	187	50	1115	0	4653	11830	5444	7376	-14.5	60.4
600	405	20	477	0	5435	7532	5706	6201	-4.8	21.5
600	370	25	596	0	5359	7772	5706	6201	-6.1	25.3
600	319	33	795	0	5219	8223	5706	6201	-8.5	32.6
600	245	50	1193	0	4877	10944	5706	6201	-14.5	76.5
700	485	20	506	0	5667	6548	5952	5382	-4.8	21.7
700	449	25	633	0	5586	6746	5952	5382	-6.1	25.3
700	389	33	844	0	5440	7126	5952	5382	-8.6	32.4
700	306	50	1266	0	5078	10260	5952	5382	-14.7	90.6
800	567	20	536	0	5893	5886	6193	4841	-4.9	21.6
800	530	25	670	0	5808	6055	6193	4841	-6.2	25.1
800	469	33	893	0	5662	6380	6193	4841	-8.7	31.8
800	372	50	1339	0	5271	9766	6193	4841	-14.9	101.8

Continued

TABLE 7. PER ACRE YIELD ESTIMATES FOR OLD FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING - CONTINUED

SITE INDEX 70 THINNING AGE 20 ROTATION AGE 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	252	20	684	0	4405	6328	4506	5782	-2.3	9.4
400	227	25	855	0	4377	6474	4506	5782	-2.9	12.0
400	195	33	1140	0	4325	6741	4506	5782	-4.0	16.6
400	151	50	1710	0	4203	7046	4506	5782	-6.7	21.9
500	314	20	753	0	4810	4881	4912	4526	-2.1	7.8
500	290	25	941	0	4781	4977	4912	4526	-2.7	10.0
500	245	33	1255	0	4729	5158	4912	4526	-3.7	14.0
500	176	50	1883	0	4603	5650	4912	4526	-6.3	24.8
600	385	20	815	0	5173	3744	5276	3581	-2.0	4.6
600	355	25	1018	0	5144	3806	5276	3581	-2.5	6.3
600	304	33	1358	0	5091	3912	5276	3581	-3.5	9.2
600	222	50	2037	0	4961	4234	5276	3581	-6.0	18.2
700	456	20	871	0	5509	2906	5613	2899	-1.9	0.2
700	420	25	1089	0	5480	2939	5613	2899	-2.4	1.4
700	367	33	1452	0	5425	3008	5613	2899	-3.4	3.7
700	269	50	2179	0	5292	3181	5613	2899	-5.7	9.7
800	536	20	925	0	5828	2334	5934	2416	-1.8	-3.4
800	484	25	1157	0	5798	2318	5934	2416	-2.3	-4.1
800	432	33	1542	0	5742	2367	5934	2416	-3.2	-2.1
800	322	50	2313	0	5605	2453	5934	2416	-5.5	1.5

Continued

TABLE 2 PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING--CONTINUED

SITE INDEX: 70 THINNING AGE: 20 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING: CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING: BD. FT.
400	254	20	684	0	5271	10310	5425	9130	-2.8	12.9
400	227	25	945	0	5226	12065	5425	9130	-3.7	32.2
400	195	33	1140	0	5141	12019	5425	9130	-5.2	31.6
400	135	50	1710	0	4934	11214	5425	9130	-9.0	22.8
500	314	20	753	0	5712	8585	5866	7514	-2.6	14.2
500	290	25	941	0	5687	8746	5866	7514	-3.4	16.4
500	245	33	1255	0	5582	9049	5866	7514	-4.8	20.4
500	176	50	1883	0	5370	10715	5866	7514	-8.5	42.6
600	385	20	815	0	6108	6585	6262	6193	-2.5	6.3
600	355	25	1018	0	6061	7263	6262	6193	-3.2	17.3
600	304	33	1358	0	5976	7507	6262	6193	-4.6	21.2
600	222	50	2037	0	5758	9760	6262	6193	-8.1	57.6
700	456	20	871	0	6473	5474	6629	5166	-2.4	6.0
700	420	25	1089	0	6426	5570	6629	5166	-3.1	7.8
700	367	33	1452	0	6337	5751	6629	5166	-4.4	11.3
700	269	50	2179	0	6115	6802	6629	5166	-7.8	31.7
800	536	20	925	0	6818	4638	6977	4389	-2.3	5.7
800	487	25	1157	0	6771	4714	6977	4389	-3.0	7.4
800	432	33	1542	0	6679	4863	6977	4389	-4.3	10.8
800	322	50	2313	0	6450	5776	6977	4389	-7.5	31.6

Clutter, Jerome L., and Earle P. Jones, Jr.
1980. Prediction of growth after thinning of old-field slash pine plantations. USDA For. Serv., Res. Pap. SE-217, 19 p. Southeast. For. Exp. Stn., Asheville, N. C.

An algorithm is given for projecting stand structure in old-field slash pine plantations from current stand statistics that represent conditions after thinning from below, or without thinning.

KEYWORDS: *Pinus elliottii*, yield, mensuration.

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Multiresource Inventories: Techniques for Evaluating Nongame Bird Habitat

by Raymond M. Sheffield

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Multiresource Inventories: Techniques for Evaluating Nongame Bird Habitat

by

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ABSTRACT.—Procedures for evaluating the suitability of forest lands for the breeding habitat of individual nongame bird species and entire avian communities are presented. A multiresource inventory of South Carolina's forest resources, conducted by Renewable Resources Evaluation (formerly Forest Survey), provides the necessary habitat data. Nine nongame bird species, representative of a broad range of habitat types, are selected as examples for evaluation. Habitat descriptions for these species were obtained from the literature and the screening criteria were formulated. The resulting estimates of habitat extent, condition, and distribution are presented.

Keywords: Wildlife habitat evaluation, habitat parameters, multiple use.

The management of forests for nongame bird species has gained considerable support in recent years. Our increasingly urbanized and environment-aware society views the intangible benefits attributed to nongame birds as being as important as the more tangible benefits attributed to game animals.

Esthetic values are not the only benefits derived from maintaining large, diverse bird populations in forest lands. DeGraaf and Payne (1975) estimated the economic value of expenditures in the United States directly attributed to the enjoyment of nongame birds in 1974 to be about $500 million. The ecological role of birds in forest ecosystems is not yet fully understood, but many studies indicate that birds may play some role in controlling insect populations (Bruns 1960; Buckner 1966; Buckner and Turnock 1965; Franz 1961; Koplin 1972; Morris and others 1958; Solomon and Morris 1970; Telford and Herman 1963; Tinbergen 1960). Another possible role is that of a monitor of environmental integrity of our forests (Plunkett 1979).

The USDA Forest Service, with other wildlife and conservation organizations, sponsored a 1975 symposium (Smith 1975) and several subsequent workshops (DeGraaf 1978a, 1978b; USDA FS 1979) on the management of our Nation's forest lands for nongame birds. The growing need for coordinated management of nongame bird habitat with timber management was addressed at these meetings. In discussing information needs for managing forest and range habitats for nongame birds at the 1975 symposium, Lennartz and Bjugstad (1975) stated that the most basic information needed was a characterization of the extent, distribution, and condition of the resource base. Such information has not been available in the United States. They suggested that avian habitat assessments be incorporated into existing regional forest inventories.

In this Paper, I demonstrate how multiresource inventory data (McClure and others 1979) collected in South Carolina may be used to estimate the suitability of large forested areas (states or portions thereof) for selected nongame bird breeding habitat. Nine nongame bird species, representing a broad range of habitat groups, are selected as examples. I present the habitat evaluation criteria for each species and resulting estimates of the extent, condition, and distribution of habitat for each.

HABITAT DATA

The data needed to evaluate the breeding habitat of the selected nongame birds were collected by U.S. Forest Service Renewable Resources Evaluation (RRE) field crews throughout South Carolina during 1977 and 1978. The South Carolina multiresource inventory is part of a nationwide pilot effort to evaluate all forest-related renewable resources. These inventories are authorized by the Forest and Rangeland Renewable Resources Research Act of 1978. More detailed information on the history and purpose of the inventories is available in a paper by McClure and others (1979).

The data were collected at 4,034 permanent sample plots established on commercial forest land throughout the State. The commercial forest acre-

age in South Carolina totals 12.5 million acres, representing a broad range of forest conditions (Sheffield 1979). The State contains a small portion of the Southern Appalachian Mountains, a large area of rolling Piedmont laced with narrow flood plains, an extensive belt of sandhills, and a broad expanse of flat coastal plain interspersed with swamps and broad flood plains. For inventory purposes, the State is divided into three Survey Units: (1) Southern Coastal Plain, (2) Northern Coastal Plain, and (3) Piedmont (fig. 1). The small mountainous area is in the Piedmont, and the sandhills in both Coastal Plain Units.

The randomly selected and systematically spaced permanent plots were previously used exclusively for collection of timber data. Little is known about the sampling procedures, levels of precision, or number of samples needed for multiresource inventories. The sampling procedures for timber, however, are designed to provide reliable estimates of area, inventory volume, growth, and removals at the Survey Unit and State levels. This study of nongame bird habitat evaluation is for the entire State in order to minimize sampling errors.

Much of the typical timber-related data collected for the past several years on RRE sample plots are useful for evaluating wildlife habitat. For instance, stand age, forest type, physiographic class, stand size, the presence of cull trees, timber volume, and tree stocking can be related to the presence or absence of breeding birds. Habitat selection by breeding birds is related to such conspicuous features of the habitat (James 1971; Lack 1933). Lennartz and McClure (1979) used six of these typical timber-related items to screen all RRE plots in the Southeast and estimate the area of potential red-cockaded woodpecker *(Picoides borealis)* nesting habitat. They found definite correlations between their estimates of potential habitat and reported population concentrations for the woodpecker.

More specialized data were collected for the evaluation of wildlife habitat; many of these items were used to evaluate habitat for the nine species. These items include the presence of natural and artificial cover factors (rock outcrops, holes, logging slash, etc.), tree cavities, snags, the occurrence of water, type of water, proximity of nonforest land uses, and percentage of forest cover. The

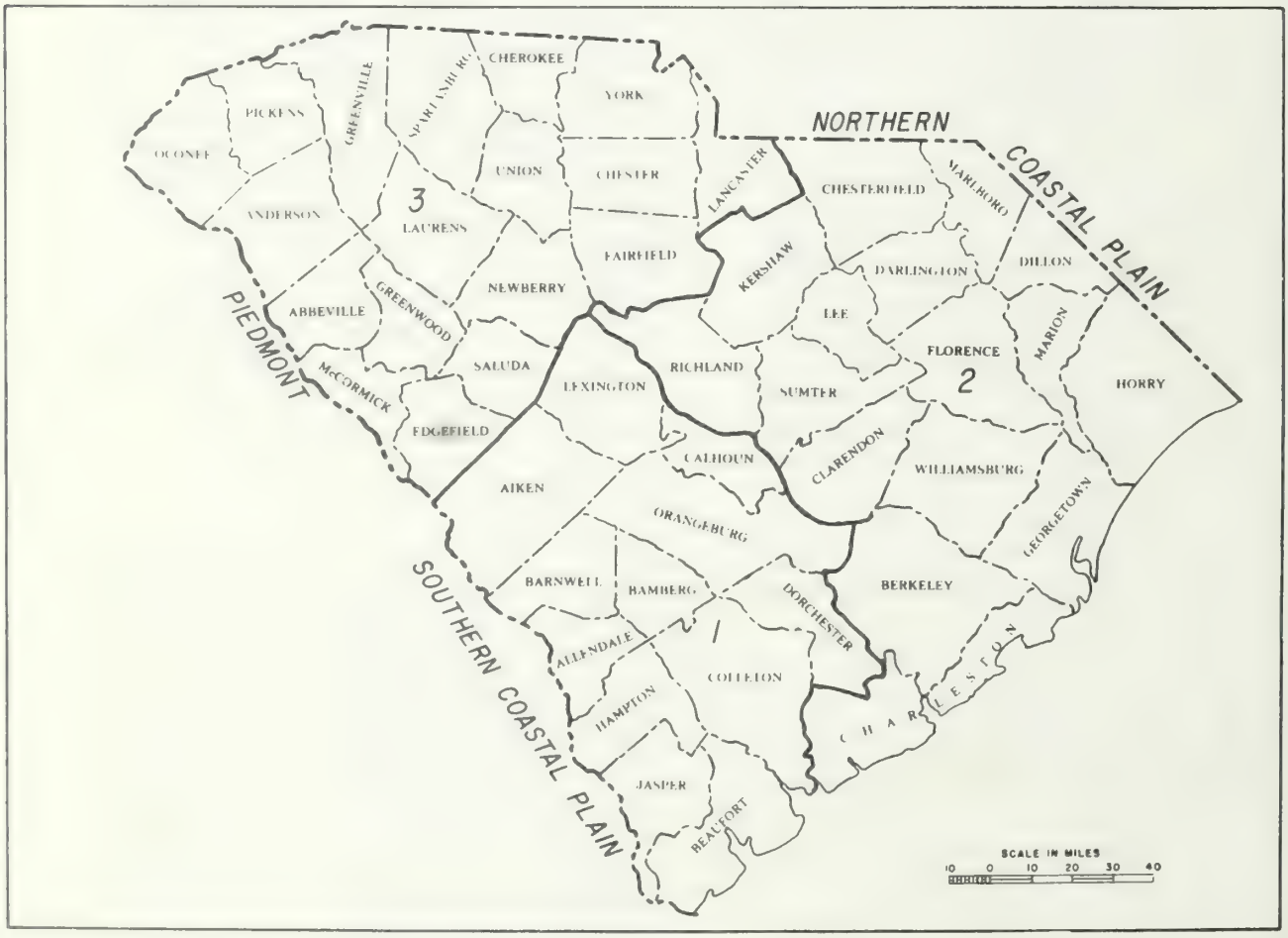


Figure 1.—Forest Survey Units in South Carolina.

tree cavity and snag data were found to be incomplete for cutover forest land and were not used as evaluation criteria; the presence of decayed cull trees was used as a substitute in some cases. This data-collection problem has been remedied in subsequent inventories.

A vegetative profile study (Cost 1979; McClure and others 1979) was incorporated into the inventory process to provide data on the lesser vegetation. When pooled with the tree tally information, these data provide a picture of the horizontal and vertical vegetative structure of the forest. This information is best depicted graphically in a profile. Figure 2 shows such a profile for a typical 20- to 39-year-old oak-hickory stand. The percentage of the total space which is occupied with vegetation within each 1-foot height zone is displayed and is referred to as "vegetative stocking" in the habitat evaluation criteria for individual bird species. To facilitate describing habitats, several vertical vegetative layers are defined. These zones are the ground layer (0 to 1 foot), shrub layer (1 to 5 feet), understory layer (5 to 15 feet), midstory layer (15 to 30 feet), and the overstory layer (30 to 80 feet). The stocking within any other defined vertical stratum may also be computed and used to evaluate habitat.

SPECIES HABITAT GROUPS AND SPECIES SELECTION

Habitat groups (or types) were selected and described to represent a range of habitats from the early to the late successional stages and with ground-to-canopy vertical foliage strata. Thus, forest habitat for bird species characteristic of early successional old fields and clearcuts, climax hardwood stands, and all vertical strata can be evaluated. A specialized bird species group was included to represent the habitat requirements of cavity-nesting bird species. Cavity nesters have been found to be an important component of the total avian community (Haapanen 1965). Other specialized bird groups such as the raptors could be included in similar specialized groups. The specialized bird group is also subdivided to represent a range of successional stages and vertical strata.

The habitat groups were used to provide a framework for evaluating entire avian communities. These groups do not necessarily represent natural groupings. A species which was selected as a representative of a particular habitat group may also be found in forest conditions characteristic of another group. The habitat groups ensure selection of species representative of a wide range of forest conditions.

The species selected for evaluation (table 1) from each habitat group is chosen merely as a member of that group and is not necessarily representative of the entire group. However, the chosen species may well be an indicator species for that group. Anderson (1979) suggests using this indicator species approach to management for avian communities. Each habitat group could be more fully evaluated by selecting several representative species for each group. Only one species is used to represent each habitat group in this Paper because the demonstration of the techniques and process of habitat evaluation for the entire range of habitat groups (and, consequently, avian communities) is more consistent with the objectives than is a complete evaluation of only one group.

The species for each habitat group were selected because, in general, they are somewhat limited in their distribution in time (successional stage) and space (vertical strata). These stenotopic species have limited adaptability to habitat variability and requirement for a specific habitat component(s) to complete some phase of their life cycle. Thus, these species provide the greatest challenge and potential for management. Wide-ranging, adaptable species—eurytopic—present little need for management because they thrive equally well in almost any habitat. This trait also makes habitat evaluation difficult. For these reasons eurytopic species were not deemed suitable for analysis by the presented methods. All selected species breed in South Carolina and other parts of the Southeast.

Ground and Shrub Habitats

The ground and shrub habitat group is characterized by the presence of a well-developed shrub stratum. In general, birds found in ground and shrub habitats nest in shrubs and low saplings or on the ground. The low vegetation also provides food and cover. The ground and shrub habitat group is divided into two subgroups based on successional age.

Early successional.—These habitats generally include the early successional old fields and areas of recent heavy timber cutting. The absence of a well-developed canopy stratum best describes these habitats. Successional age of these habitats may vary considerably, depending on the level of stocking in a particular area. For instance, an old field supporting a dense stocking of pine may form a closed canopy between 10 and 20 years. But the same old field with only scattered trees may qualify as early successional shrub habitat for 20 to 30 years or more. The prairie warbler is selected for habitat evaluation for this habitat group.

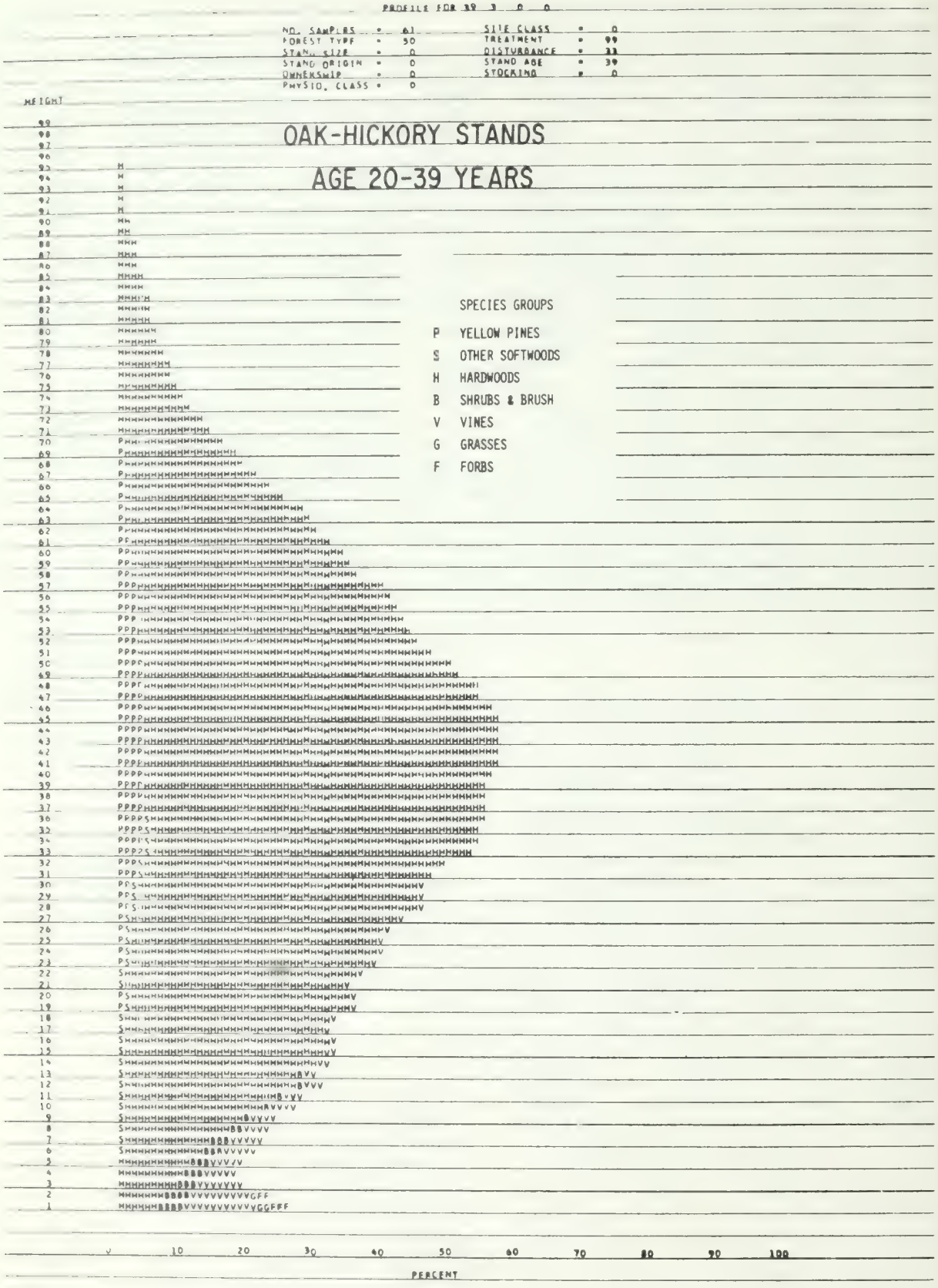


Figure 2.—Horizontal and vertical structure of broad classes of plants for oak-hickory stands, 20 to 39 years, Piedmont, South Carolina, 1977.

Table 1.—Selected nongame bird species with symbols used in tables 3, 4, and 5

Species	Symbol	Scientific name
Brown-headed nuthatch	BRNU	*Sitta pusilla*
Downy woodpecker	DOWO	*Dendrocopus pubescens*
Eastern bluebird	EABL	*Sialia sialis*
Pileated woodpecker	PIWO	*Dendrocopus pileatus*
Pine warbler	PINW	*Dendroica pinus*
Prairie warbler	PRWA	*Dendroica discolor*
Prothonotary warbler	PROW	*Protonotaria citrea*
Red-eyed vireo	REVI	*Vireo olivaceus*
Wood thrush	WOTH	*Hylocichla mustelina*

Late successional.—Late successional ground and shrub habitats are characterized by the presence of a shrub stratum beneath a well-developed canopy. This condition is most often found in mature hardwood stands, but may exist in older pine and the transitional oak-pine stands. The wood thrush is selected for evaluation from this group.

Canopy Habitats

A well-developed overstory layer in forests provides the canopy habitat. Shrub, understory, and midstory strata may be present but are not a necessary requirement for all canopy-dwelling bird species. Some species may require other strata for nesting, but the overstory stratum is the primary requirement. This habitat group is divided into two subgroups based on successional age.

Pine forests.—Forests in which pine species *(Pinus* spp.*)* make up a substantial portion of the overstory stratum are home to several bird species. Some of these birds occur at their greatest density in pure pine stands and decrease in numbers with the invasion of hardwood species. The pine warbler is typical of such population trends and is selected for habitat evaluation.

Hardwood forests.—Hardwood canopy habitats consist of a well-developed overstory stratum made up mostly of hardwood species. Birds belonging to this group generally appear with the emergence of hardwood trees into the canopy of pine forests and increase until a mature hardwood stand exists. The red-eyed vireo is a typical representative of this group and is selected for evaluation.

Specialized Bird Habitats

The specialized bird habitat group is separated into primary cavity nesters (species that excavate their own hole) and secondary cavity nesters (species that use natural cavities and woodpecker holes for nesting).

Primary cavity nesters.—This group is represented by two woodpeckers in this Paper—the pileated woodpecker and the downy woodpecker. The pileated woodpecker is characteristic of dense, mature hardwood and pine forests. Less mature, open forests are the most characteristic habitat of the downy woodpecker.

Secondary cavity nesters.—This group is represented by three species, each somewhat characteristic of a particular forest condition. Mature pine stands are represented by the brown-headed nuthatch, bottomland hardwood stands by the prothonotary warbler, and clearcuts and open forests by the eastern bluebird.

TECHNIQUES FOR DETERMINING HABITAT SUITABILITY

A major problem in quantifying the habitats of nongame birds is that most available habitat information is qualitative in nature rather than quantitative (Hooper and Crawford 1969). Some of the more recent research studies (Anderson and Shugart 1974a, 1974b; Conner and Adkisson 1977; James 1971; Shugart and others 1975; Whitmore 1975, 1977) have used quantitative methods to relate the occurrence of bird species to specific habitat variables but, in general, have stopped short of providing precise habitat guidelines for a particular bird species. For instance, what is the optimum tree stocking, species composition, or vegetative coverage within any particular vertical layer for a certain species? At a recent symposium and workshop on nongame birds, this lack of information was identified as a major deterrent to nongame bird management (DeGraaf 1978a; Smith 1975).

In this study, each sample stand is ranked as either unsuitable habitat or as good, acceptable, or poor habitat for each species. To rank these stands or habitats in this manner, quantitative guidelines

had to be established for each habitat parameter determined from the literature to be important to each species' occurrence. Since such guidelines were usually absent from the literature, the importance of each habitat criterion and the dividing lines between the various habitat rankings were determined subjectively. Empirical research results should replace these judgments in the future.

The first step in ranking is to determine which habitat parameters are of major importance to a particular species' occurrence. The dividing line between suitable and unsuitable for each habitat parameter is established, and each sample stand not qualifying as suitable for any of these parameters is given an overall rank of unsuitable (code 0) for that particular species. For example, suppose species X can exist only in forests consisting mainly of pine trees 30 years of age and older with well-developed vegetative layers below the overstory. Sample stands will be ranked as unsuitable habitat for species X unless the stands are composed of mostly pine trees (50 percent or more of the total basal-area tree stocking) with a stand age of 30 years or more, and with 15 percent or greater vegetative stocking in any 1-foot stratum below the overstory, excluding the 0- to 1-foot zone. All stands meeting each of these three requirements for species X habitat are suitable and are further ranked as good (code 3), acceptable (code 2), or poor (code 1) habitat.

Ranking suitable habitats as good, acceptable, or poor is accomplished by considering all habitat parameters of any importance to a species' occurrence. These variables are usually further refinements of ones used in the initial separation of unsuitable and suitable habitats, but other, less crucial, variables may be considered if they contribute to a species' occurrence in a particular habitat. Each habitat variable is subjectively divided into good, acceptable, and poor segments based on the range of values possible for that variable, excluding the unsuitable segments. All identified habitat variables are then assigned numerical values based on whether the variable for the sample stand falls in the good (3 points), acceptable (2 points), or poor (1 point) range. Habitat rank is then determined from the number of points accumulated out of the total possible. For example, the ranking criteria for species X are:

Unsuitable habitats.—Sample stand does not qualify as suitable habitat if any of the following conditions exist:

1. Proportion of live-tree stocking made up of pine species is less than 50 percent.
2. Stand age is less than 30 years.
3. All 1-foot strata in the shrub, understory, and midstory layers are less than 15 percent stocked with vegetation.

Suitable habitats.—Sample stands classified as suitable habitat are ranked according to the total number of points accumulated from consideration of the following items (point values in parentheses).

1. Proportion of live-tree stocking made up of pine species:
   a. 80 percent or more (3)
   b. 65-79 percent (2)
   c. 50-64 percent (1)
2. Stand age:
   a. 70 years or more (3)
   b. 50-69 years (2)
   c. 30-49 years (1)
3. Vegetative stocking in 1-foot stratum of highest density in the shrub, understory, or midstory layers:
   a. 65 percent or more (3)
   b. 40-64 percent (2)
   c. 15-39 percent (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	8-9
Acceptable	2	5-7
Poor	1	3-4
Unsuitable	0	0

Using these criteria, a stand consisting of only pine species 40 years old with a maximum vegetative stocking in any 1-foot stratum in the shrub, understory, or midstory of 25 percent would be assigned a total of 5 points and would qualify as acceptable habitat. For this example and for the following nine species, it is not possible for a plot to be assigned the total point values between 0 and the minimum number of points shown because of the screening logic.

SELECTED SPECIES HABITAT CRITERIA

The criteria for describing and evaluating the habitat of each selected species are taken from the available literature for each bird.

Prairie Warbler

The primary breeding habitats of the prairie warbler are located in the earliest stages of a successional continuum. Intermediate or greater shrub densities are necessary (James 1971). The shrub layer is important since the prairie warbler nests in shrubs and low trees (Bent 1953; Burleigh 1958; Griscom and Sprunt 1957). These early successional habitats may be the result of old-field succession (Johnston and Odum 1956; Parnell 1969; Shugart; and James 1973; Sprunt and Chamberlain 1970) or timber cutting (Ambrose 1975; Bent 1953; Hooper 1967; Noble and Hamilton 1976; Oelke 1966; Parnell 1964). Meyers and Johnson's (1978) analysis of

numerous breeding bird censuses also confirms that prairie warblers occur at highest densities in the youngest stands. Some older forest stands provide suitable habitat, provided the overstory layer is relatively open and a shrub layer is well developed (Burleigh 1958; Noble and Hamilton 1976).

The habitat screening criteria for the prairie warbler were developed from the preceding literature citations. The presence of a well-developed shrub stratum in stands without a closed canopy is an overriding factor in separating suitable habitats from unsuitable ones. Stand age is also important, with the younger stands qualifying as suitable and the older stands as unsuitable unless the canopy is open. The same three factors are used to rank the suitable habitats into good, acceptable, and poor classes. The criteria for evaluating prairie warbler habitat are:

Unsuitable habitats.

1. Vegetative stocking in any 1-foot stratum more than 25 feet above the ground is 75 percent or more.
2. All 1-foot strata in the shrub layer are less than 15 percent stocked with vegetation.
3. Stand age is greater than 30 years unless overstory layer stocking by 1-foot strata is less than 40 percent.

Suitable habitats.

1. Vegetative stocking in 1-foot stratum of highest density above the 25-foot level:
   a. 0-24 percent (3)
   b. 25-49 percent (2)
   c. 50-74 percent (1)
2. Vegetative stocking in 1-foot stratum of highest density in the shrub layer:
   a. 50-100 percent (3)
   b. 30-49 percent (2)
   c. 15-29 percent (1)
3. Stand age:
   a. 0-10 years (3)
   b. 11-20 and 31 or more years (2)
   c. 21-30 years (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	8-9
Acceptable	2	6-7
Poor	1	3-5
Unsuitable	0	0

Wood Thrush

Wood thrush breeding habitats are opposite to those of the prairie warbler. Mature, climax hardwood stands appear to be the preferred breeding habitat of the wood thrush, provided a light to moderate shrub or understory stratum is present (Bertin 1977; Brackbill 1943; DeGraaf 1976; James 1971; Johnston and Odum 1956; Shugart and James 1973; Willson 1974). Since the wood thrush nests at an average height of 10 feet aboveground (Bent 1949; McElroy 1974), the shrub and understory layers are important.

The habitat screening criteria for the wood thrush uses stand age, the presence of shrub and understory layers, and a well-developed overstory layer as the variables to determine whether a sample stand is classified as suitable or unsuitable. Meyers and Johnson's (1978) study indicates that the wood thrush is tolerant of a range of habitats from pine stands 25 to 30 years old to their favored mature hardwood stands. Several sources indicate that the wood thrush prefers the more mesic forest stands for breeding (Bent 1949; Bertin 1977; Shugart and James 1973). Hence, the ranking of suitable habitats uses forest type and the presence and type of water on the stand, in addition to the variables used to separate suitable and unsuitable habitats. The habitat screening criteria for the wood thrush are:

Unsuitable habitats.

1. Stand age is less than 25 years, unless there is 50 percent or better vegetative stocking in the 1-foot stratum of highest density in the overstory.
2. All 1-foot strata in the shrub and understory layers are less than 15 percent stocked with vegetation.
3. All 1-foot strata in the overstory layer are less than 30 percent stocked with vegetation.

Suitable habitats.

1. Forest type:
   a. Hardwood types, except oak-gum-cypress (3)
   b. Oak-pine types (2)
   c. Pine types and oak-gum-cypress (1)
2. Stand age:
   a. 75 years or more (3)
   b. 50-74 years (2)
   c. 0-49 years (1)
3. Vegetative stocking in 1-foot stratum of highest density in the shrub layer:
   a. 50 percent or more (3)
   b. 30-49 percent (2)
   c. 15-29 percent (1)
4. Vegetative stocking in 1-foot stratum of highest density in the understory layer:
   a. 50 percent or more (3)
   b. 30-49 percent (2)
   c. 15-29 percent (1)
5. Vegetative stocking in 1-foot stratum of highest density in the overstory layer:

a. 75 percent or more (3)
b. 50-74 percent (2)
c. 30-49 percent (1)

6. Presence of water:
   a. Permanent water on sample acre (3)
   b. Permanent water in stand adjacent to but not on sample acre (2)
   c. Temporary water on sample acre or in adjacent stand (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	14-18
Acceptable	2	10-13
Poor	1	5-9
Unsuitable	0	0

Pine Warbler

Griscom and Sprunt (1957) state that the pine warbler is strictly a bird of the pine forests and is hardly ever seen far from pine trees it uses for nesting. Anderson and Shugart (1974a, 1974b) found that the pine warbler selects its habitat most strongly on the basis of number of canopy trees, size of canopy vegetation, and average size of understory vegetation. Pine warblers were most common in areas with a dense canopy and sparse understory. They occur at highest densities in pure pine stands, at lesser densities in oak-pine stands, and disappear with the pine trees in pure hardwood stands (Cleaveland 1973; Dickson and Segelquist 1979; Noble and Hamilton 1976; Oelke 1966; Parnell 1969; Reese 1976). Most adequately stocked pine stands 15 years old and older offer suitable habitat for pine warblers (Meyers and Johnson 1978).

The habitat screening criteria for the pine warbler incorporate three variables in identifying suitable habitats—forest type, stand age, and pine vegetative stocking in the overstory. The overstory layer is considered to begin at 20 feet from the ground for the pine warbler because of the relatively young age of some suitable habitats. Exclusion of forest types other than pine or oak-pine permits stands to be classified as suitable only if 25 percent or more of the tree stocking is made up of pine species. Suitable habitats are ranked on the basis of three variables—pine vegetative stocking above the 20-foot level, total pine basal-area stocking, and shrub and understory vegetative stocking. The most favorable habitats are those with the lowest shrub and understory layer stocking. Stand age is not used to rank suitable habitats, since evidence suggests that habitat suitability does not increase appreciably with stand maturity (Meyers and Johnson 1978). The screening criteria for the pine warbler are:

Unsuitable habitats.

1. Forest type is other than pine or oak-pine.
2. Stand age is less than 15 years, unless pine vegetative stocking in 1-foot stratum of highest density in the overstory is 40 percent or greater.
3. Pine vegetative stocking in all 1-foot strata more than 20 feet above ground is less than 30 percent.

Suitable habitats.

1. Pine vegetative stocking in 1-foot stratum of highest density above the 20-foot level:
   a. 75 percent or more (3)
   b. 50-74 percent (2)
   c. 30-49 percent (1)
2. Total pine basal area per acre:
   a. 60 square feet or more (3)
   b. 35-59 square feet (2)
   c. 10-34 square feet (1)
3. Vegetative stocking in 1-foot stratum of highest density in the shrub and understory layers:
   a. Less than 30 percent (3)
   b. 30-59 percent (2)
   c. 60 percent or more (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	8-9
Acceptable	2	5-7
Poor	1	2-4
Unsuitable	0	0

Red-eyed Vireo

The red-eyed vireo is found to some extent in many forest conditions and probably has a somewhat broad environmental tolerance (Beals 1960). However, mature hardwood stands support the highest numbers of this bird, while pure pine stands do not provide suitable habitat (Bond 1957; DeGraaf 1976; James 1971; Johnston and Odum 1956; Kendeigh 1945; Lawrence 1953). Lawrence (1953) found no red-eyed vireos where less than 25 percent of the total basal area consisted of broadleaf trees. The presence of a well-developed overstory stratum is of major importance to the red-eyed vireo (Anderson and Shugart 1974a, 1974b; DeGraaf 1976) because it feeds on broadleaf canopy foliage insects (Bent 1950). But the presence of subcanopy stratification has also been shown to be of importance to red-eyed vireo occurrence (Anderson and Shugart 1974a, 1974b; James 1976; Lawrence 1953; Shugart and James 1973). Shrubs, saplings, and low tree branches are used by the red-

eyed vireo for nesting (Bent 1950), usually at 5 to 20 feet above ground.

The habitat screening criteria used in identifying suitable habitats include the percentage of total basal area comprised of hardwood species, stand age, and vegetative stocking in the overstory layer and layers below the overstory. Ranking of suitable habitats is based on the same criteria.

These criteria are:

Unsuitable habitats.

1. Less than 25 percent of the total basal area is made up of hardwood tree species.
2. Stand age is less than 20 years unless hardwood vegetative stocking in the 1-foot stratum of highest density in the overstory is 50 percent or more.
3. All 1-foot strata in the 5- to 30-foot layer are less than 15 percent stocked with vegetation.
4. All 1-foot strata in the overstory layer are less than 30 percent stocked with broadleaf vegetation.

Suitable habitats.

1. Proportion of total basal area made up of hardwood species:
   a. 75 percent or more (3)
   b. 50-74 percent (2)
   c. 25-49 percent (1)
2. Stand age:
   a. 70 years or more (3)
   b. 45-69 years (2)
   c. 0-44 years (1)
3. Vegetative stocking in 1-foot stratum of highest density in the midstory layer:
   a. 50 percent or more (3)
   b. 30-49 percent (2)
   c. 15-29 percent (1)
4. Vegetative stocking in 1-foot stratum of highest density in the understory layer:
   a. 50 percent or more (3)
   b. 30-49 percent (2)
   c. 15-29 percent (1)
5. Hardwood vegetative stocking in 1-foot stratum of highest density in the overstory layer:
   a. 75 percent or more (3)
   b. 50-74 percent (2)
   c. 30-49 percent (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	13-15
Acceptable	2	9-12
Poor	1	4-8
Unsuitable	0	0

Pileated Woodpecker

The pileated woodpecker prefers dense, mature forests for its breeding habitats (Conner and Adkisson 1977; Hardin and Evans 1977). However, coniferous and deciduous forests with medium-sized sawtimber (15 to 18 inches diameter at breast height, d.b.h.) will provide adequate pileated nest trees if some of the trees are decayed or dead (Conner and others 1975). The presence of decay in pileated nest trees is apparently necessary to allow cavity excavation into the heartwood. Conner and others (1976) found that all pileated woodpecker nest trees examined in southwest Virginia were infected by fungal heartrots. Old-growth stands provide optimal habitat because these fungal heartrots have had time to infest numerous trees and the trees are large enough to contain large cavities. But somewhat younger stands can provide adequate habitat, especially those with large residual trees left from prior timber cuttings.

Stand density and the presence of nearby water appears to have an effect on the suitability of a stand for pileated breeding habitat. Conner and Adkisson (1977) and Conner and others (1975) found pileated nest trees only in dense stands (137 square feet of basal area per acre) in southwest Virginia. Pileated nest trees are almost always near a supply of water (Conner and Adkisson 1977; Hooper 1967; Hoyt 1957). The percentage of the area around their nests in forest cover is also important because the pileated tends to favor the heavily forested areas and reject the lightly forested, highly dissected ones (Conner and Adkisson 1977; Sprunt and Chamberlain 1970).

The variables used to identify suitable pileated woodpecker habitat are stand age, vegetative stocking in the overstory, and percentage of forest cover. The overstory layer begins at the 40-foot level for the evaluation of this species' habitat. Variables used in ranking suitable habitats include the presence of water on or near the stand, the presence of medium to large sawtimber trees containing appreciable decay, and the three variables listed above. The criteria for evaluating pileated woodpecker habitat are:

Unsuitable habitats.

1. Stand age is less than 40 years for bottomland forest types and less than 50 years for all other types.
2. All 1-foot strata above the 40-foot vertical level are less than 25 percent stocked with vegetation.
3. A 450-acre circular area with the sample stand as the center is less than 36 percent forest land.

Suitable habitats.

1. Stand age:
   a. Bottomland and pine types—80 years or more; other types—99 years or more (3)
   b. Bottomland types—60 to 79 years; pine types—65 to 79 years; other types—75 to 98 years (2)
   c. Bottomland types—40 to 59 years; pine types—50 to 64 years; other types—50 to 74 years (1)
2. Vegetative stocking in 1-foot stratum of highest density above the 40-foot level:
   a. 80 percent or more (3)
   b. 50-79 percent (2)
   c. 25-49 percent (1)
3. Presence of water:
   a. Permanent water on sample acre (3)
   b. Permanent water in stand adjacent to but not on sample acre (2)
   c. Temporary water on sample acre or in adjacent stand (1)
4. Percent forest land in 450-acre area surrounding sample acre:
   a. 76 percent or more (3)
   b. 56-75 percent (2)
   c. 36-55 percent (1)
5. Square feet of basal area per acre in trees 15 inches d.b.h. and larger with 20 percent or more volume loss due to decay:
   a. 8 or more (3)
   b. 4-7 (2)
   c. 0-3 (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	13-15
Acceptable	2	9-12
Poor	1	4-8
Unsuitable	0	0

Downy Woodpecker

The downy woodpecker is found in yards, gardens, and roadsides as well as in numerous forested conditions. In forests, its breeding habitats are found in earlier successional stages than are those of the pileated woodpecker (Bond 1957; Conner and Adkisson 1977). Thus, downy nests are located in stands of smaller trees and lower basal area than are those of the pileated (Conner and others 1975).

Anderson and Shugart (1974a, 1974b) found that downy occurrence was highly correlated with the number of sapling trees—stands with high numbers of sapling trees supported a higher number of downy woodpeckers than did stands with few sapling trees. Downies apparently spend much of their time foraging on these small trees in the subcanopy strata (Williams 1975). This habit allows them to breed in recently timbered areas provided that enough nest trees are available (Ambrose 1975). Adequate nesting sites are provided by snags and live trees infected with fungal heartrots (Conner and others 1976). Conner and others (1975) state that stands with trees averaging 8 to 12 inches d.b.h. will provide adequate nesting sites if some of the trees are decayed.

The variables considered most important to downy occurrence and used to identify suitable habitats include stand age, vegetative stocking in the understory and midstory layers, the presence of residual trees in young stands, and the number of saplings per acre. Variables used in ranking suitable habitats include stand age, the number of saplings per acre, basal area per acre, and the presence of trees 9 inches d.b.h. and larger containing appreciable decay. The criteria are:

Unsuitable habitats.

1. Stand age is 11 to 29 years.
2. There are less than 200 saplings per acre.
3. All 1-foot strata in the understory or midstory layers are less than 15 percent stocked with vegetation.
4. For stands age 10 or less, there is less than 10 square feet of basal area per acre in trees 9 inches d.b.h. and larger.

Suitable habitats.

1. Stand age:
   a. 60 years or more (3)
   b. 45-59 and 0-10 years (2)
   c. 30-44 years (1)
2. Number of saplings per acre:
   a. 900 or more (3)
   b. 500-899 (2)
   c. 200-499 (1)
3. Square feet of basal area per acre:
   a. 35-70 (3)
   b. 20-34 or 71-90 (2)
   c. Less than 20, or more than 90 (1)
4. Square feet of basal area per acre in trees 9 inches d.b.h. and larger with 20 percent or more volume loss due to decay:
   a. 8 or more (3)
   b. 4-7 (2)
   c. 0-3 (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	10-12
Acceptable	2	7-9

Poor	1	4-6
Unsuitable	0	0

Brown-headed Nuthatch

The brown-headed nuthatch prefers the open, mature pine forests of the Southeastern United States for its breeding habitat. Younger pine forests and mixed pine-hardwood stands provide less favorable but suitable habitats, while extremely young pine stands and pure hardwood stands provide no suitable habitat (Bent 1948; Cleaveland 1973; Johnston and Odum 1956; McElroy 1974; Meyers and Johnson 1978; Noble and Hamilton 1976; Oelke 1966; Scott and others 1977; Sprunt and Chamberlain 1970). The brown-headed nuthatch nests low to the ground in cavities excavated in decayed tree stubs, stumps, or fence posts (Norris 1958). They are often found in burned-over pine forests since fire creates the preferred open understory and needed nesting sites (Bent 1948; McElroy 1974; Sprunt and Chamberlain 1970).

The habitat variables deemed most important to brown-headed nuthatch occurrence are stand age, percentage of total basal area made up of pine species, and pine vegetative stocking in the overstory layer. These variables are used to identify suitable habitats. Additional variables used in ranking suitable habitats are vegetative stocking in the shrub and understory strata and the occurrence of fire in the recent past. The habitat screening criteria for the brown-headed nuthatch are:

Unsuitable habitats.

1. Stand age is less than 20 years.
2. Less than 50 percent of the total basal area is made up of pine species.
3. Pine vegetative stocking in all 1-foot strata in the overstory is less than 40 percent.

Suitable habitats.

1. Stand age:
   a. 60 years or more (3)
   b. 40-59 years (2)
   c. 20-39 years (1)
2. Proportion of total basal area made up of pine species:
   a. 80 percent or more (3)
   b. 65-79 percent (2)
   c. 50-64 percent (1)
3. Vegetative stocking in 1-foot stratum of highest density in the 2- to 15-foot vertical layer:
   a. 0-30 percent (3)
   b. 31-60 percent (2)
   c. 61 percent or more (1)
4. Pine vegetative stocking in 1-foot stratum of highest density in the overstory layer:
   a. 80 percent or more (3)
   b. 60-79 percent (2)
   c. 40-59 percent (1)
5. History of fire occurrence on sample stand:
   a. Burned within past year (3)
   b. Burned 1 to 3 years ago (2)
   c. Burned over 3 years ago, or no history of fire (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	13-15
Acceptable	2	9-12
Poor	1	5-8
Unsuitable	0	0

Prothonotary Warbler

The prothonotary warbler limits its choice of breeding habitats to swamps, river bottoms, and other low-lying, frequently flooded areas (Bent 1953; Parnell 1969). Nests are placed in natural cavities and woodpecker holes in snags, stumps, and decayed cypress knees (Griscom and Sprunt 1957; Simpson 1969). The presence of standing or running water near the nest site appears to be of utmost importance for the prothonotary. For instance, Walkinshaw (1953) found in a Michigan study that all 84 established territories of this warbler were in the immediate vicinity of running or standing water or in easily flooded locations. The nests were usually shaded most of the day, making the presence of a thick tree canopy a prerequisite. Other attributes of prothonotary warbler habitat include the absence of a dense shrub layer and intermediate to mature successional ages (James 1971).

In South Carolina and throughout the Southeast, prothonotary warblers occur at highest densities in the coastal swamps, but are also found in flood plain forests in the Piedmont regions (Reese 1976; Simpson 1969; Sprunt and Chamberlain 1970). The habitat screening criteria should handle identification of suitable habitats in either area. The criteria used to separate suitable and unsuitable habitats are numerous. They include physiographic class, presence of water or proximity to water, shrub layer vegetative stocking, overstory layer vegetative stocking, and stand age. These same variables, excepting physiographic class, are used to rank suitable habitats. The criteria are:

Unsuitable habitats.

1. Physiographic class is other than the following: stream margin, deep swamp, cypress strand, small drain, cypress pond, or willow heads and strands.
2. There is no water (permanent or temporary) recorded on the sample acre or in the adjacent stand, or if the plot is not within 300 feet of a stream

greater than 30 feet in width.

3. Vegetative stocking in 1-foot stratum of highest density in the shrub layer is greater than 60 percent.

4. All 1-foot strata in the overstory layer are less than 40 percent stocked with vegetation.

5. Stand age is less than 30 years.

Suitable habitats.

1. Presence of water or proximity to streams:
   a. Permanent water on sample acre, or less than 119 feet from stream (3)
   b. Permanent water in stand adjacent to but not on sample acre, or 119 to 200 feet from stream (2)
   c. Temporary water on sample acre or adjacent stand, or 201 to 300 feet from stream (1)
2. Vegetative stocking in 1-foot stratum of highest density in the shrub layer:
   a. 0-20 percent (3)
   b. 21-40 percent (2)
   c. 41-60 percent (1)
3. Vegetative stocking in 1-foot stratum of highest density in the overstory layer:
   a. 80 percent or more (3)
   b. 60-79 percent (2)
   c. 40-59 percent (1)
4. Stand age:
   a. 80 years or more (3)
   b. 50-79 years (2)
   c. 30-49 years (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	10-12
Acceptable	2	7-9
Poor	1	4-6
Unsuitable	0	0

Eastern Bluebird

The eastern bluebird typically inhabits open pine stands and clearings, and nests in old woodpecker holes in standing dead trees (Burleigh 1958; Scott and others 1977; Thomas 1946). The early stages of succession following field abandonment or clearcutting are beneficial to the eastern bluebird (Shugart and James 1973). Conner and Adkisson (1974, 1975) found that 1-year-old clearcut areas provide excellent breeding habitat for bluebirds if nest cavities are available. Clearcuts up to 12 years old provide suitable habitat. As stands grow older the vegetation grows taller and more dense, thus detracting from its suitability as bluebird habitat. Bluebirds are known to select areas with abundant open ground (Thomas 1946). Heard (1979) studied eastern bluebird nesting success in clearcuts of varying ages in eastern North Carolina and found that nesting success in artificial boxes placed in 1- to 3-year-old clearcuts was more than double that of boxes placed in 4- to 8-year-old pine stands. She also confirmed the observations of other authors (Pinkowski 1976; Scott and others 1977) that eastern bluebirds readily nest in the savannahlike habitats of older pine stands.

The habitat criteria used in identifying and ranking eastern bluebird habitats reflect the two stages of suitable habitats. Stands falling between the early clearcut stages and the somewhat older pine stands are excluded. Other variables used to identify suitable habitats include forest type, vegetative stocking in the understory layer, basal area per acre, and vegetative stocking in the overstory layer. Only three variables are used to rank suitable habitats—stand age, vegetative stocking in the understory layer, and the history of fire occurrence. Fire maintains the favored open ground and creates potential nesting substrates. The habitat screening criteria for the eastern bluebird are:

Unsuitable habitats.

1. Stand age is 13 to 19 years.

2. Forest type is not pine for stands 20 years old and greater.

3. For stands 0 to 12 years old, vegetative stocking in the 1-foot stratum of highest density in the understory layer is 60 percent or greater.

4. For stands 20 years old and greater, vegetative stocking in the 1-foot stratum of highest density in the understory layer is 40 percent or greater.

5. Basal area per acre is greater than 60 square feet.

6. Vegetative stocking in 1-foot stratum of highest density in the overstory layer is greater than 50 percent.

Suitable habitats.

1. Stand age:
   a. 0-3 or 60 years and more (3)
   b. 4-8 or 40-59 years (2)
   c. 9-12 or 20-39 years (1)
2. Vegetative stocking in the 1-foot stratum of highest density in the understory layer:
   a. 0-15 percent (3)
   b. 16-30 percent (2)
   c. 31 percent or more (1)
3. History of fire in sample stand:
   a. Within past year (3)
   b. 1 to 3 years ago (2)
   c. Over 3 years ago, or no history of fire in stand (1)

Habitat Rank Determination

Habitat rank	*Code*	*Total accumulated points*
Good	3	8-9
Acceptable	2	6-7
Poor	1	3-5
Unsuitable	0	0

RESULTS

A FORTRAN program was written incorporating the criteria presented. The program evaluated each RRE forest sample in South Carolina, using the available habitat data, and ranked each sample stand in terms of its suitability for breeding habitat for the nine nongame bird species. Summary cards for each plot were produced with the rankings along with other basic data about the stand. These summary cards were used for compiling and evaluating the data. The estimates of the extent, relative condition, and distribution of habitat are presented in this section.

When interpreting these data, the reader should keep in mind that the criteria used to estimate area of habitat are based on general habitat descriptions, with modifications to allow incorporation of RRE data. For this reason, the results presented are intended to be examples and not bold forecasts of the acreages in South Carolina on which one should find each of the nine species. The results do show some expected differences between species, ownership, and regions within the State.

Habitat Extent and Conditions

The acreages of habitat by suitability and species are presented in table 2. The results seem consistent with the qualitative descriptions of habitat and species abundance obtained from the literature. For instance, the eastern bluebird and the prothonotary warbler are probably the most restrictive of the nine species in their selection of habitat; these two species have the least acreage of suitable habitat. The prairie warbler is somewhat less restrictive, resulting in about 25 percent of the forest land being classified as suitable. However, most of this suitable acreage was ranked as either good or acceptable habitat. The pileated woodpecker and the brown-headed nuthatch, both species of some concern to ornithologists, have between 26 and 30 percent of the commercial forests in suitable habitat. However, both species have 10 percent or less of their total suitable acreage ranked as good habitat. The species with the most suitable habitat include the downy woodpecker, wood thrush, red-eyed vireo, and the pine warbler. The literature suggests that these species may have more tolerance to habitat variability than do the other five species. This tolerance is probably reflected by the screening criteria. Various natural and man-related forces may have combined to create or sustain abundant suitable habitat for these and other species.

Habitat Distribution

Computer generated habitat maps, based on actual plot locations, for each of the nine species

Table 2.—Acreage of suitable and unsuitable nongame bird habitat, by suitability rank and species, South Carolina, 1978

Species	Total	Suitability rank			
		Good	Acceptable	Poor	Unsuitable
		Thousand acres			
Prairie warbler	12,502.9	1,165.6	1,246.8	759.5	9,331.0
Wood thrush	12,502.9	646.2	3,368.2	2,135.5	6,353.0
Pine warbler	12,502.9	1,823.0	2,633.1	825.0	7,221.8
Red-eyed vireo	12,502.9	1,418.9	3,400.4	659.9	7,023.7
Pileated woodpecker	12,502.9	329.0	1,651.1	1,228.1	9,294.7
Downy woodpecker	12,502.9	431.1	3,760.9	2,541.7	5,769.2
Brown-headed nuthatch	12,502.9	101.5	2,680.5	933.9	8,787.0
Prothonotary warbler	12,502.9	606.9	661.8	42.2	11,192.0
Eastern bluebird	12,502.9	147.4	613.1	731.7	11,010.7

(figs. 3-11) show the distribution of good, acceptable, and poor habitat in South Carolina. Although these maps also reflect the habitat acreage given in table 2, their greatest value is in identifying concentrations of suitable habitat for a particular species as well as areas where suitable habitat is sparse or absent.

Most of the nine species exhibit some differences in habitat distribution. Those species that are most restrictive in their selection of habitat show the most striking differences. In this study, these species include the prairie warbler, pileated woodpecker, brown-headed nuthatch, prothonotary warbler, and the eastern bluebird. These species also have the smallest acreage of suitable habitat.

The prairie warbler (see fig. 3) has more abundant habitat in the Coastal Plain region, where several concentrations are located, than in the Piedmont and mountainous regions. Stands sparsely stocked with trees reaching into the overstory layer combined with dense vegetative stocking in the shrub layers are more abundant in the Coastal Plain region than in the Piedmont. Suitable habitat for the pileated woodpecker (see fig. 7) is concentrated in the Coastal Plain and the small mountainous area. These concentrations are caused by the older stand ages in these two regions. In the Coastal Plain, the older stands, and thus the better pileated habitat, are located in the swamps and river bottoms. Suitable habitat for the brown-headed nuthatch (see fig. 9) is fairly uniformly distributed across the State with the exception of the northwest Piedmont and mountains, where suitable habitat is less dense. However, about 84 percent of the good habitat is located in the Coastal Plain. Only 16 percent of the prothonotary warbler habitat (see fig. 10) is located in the Piedmont. In the Coastal Plain, suitable habitat is heavily concentrated along the major rivers and in the swamps. Suitable eastern bluebird habitat is about proportionally distributed throughout the State in terms of total acreage, but the Coastal Plain has more noticeable concentrations of acceptable to good habitat (see fig. 11).

DISTRIBUTION OF SUITABLE
PRAIRIE WARBLER HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

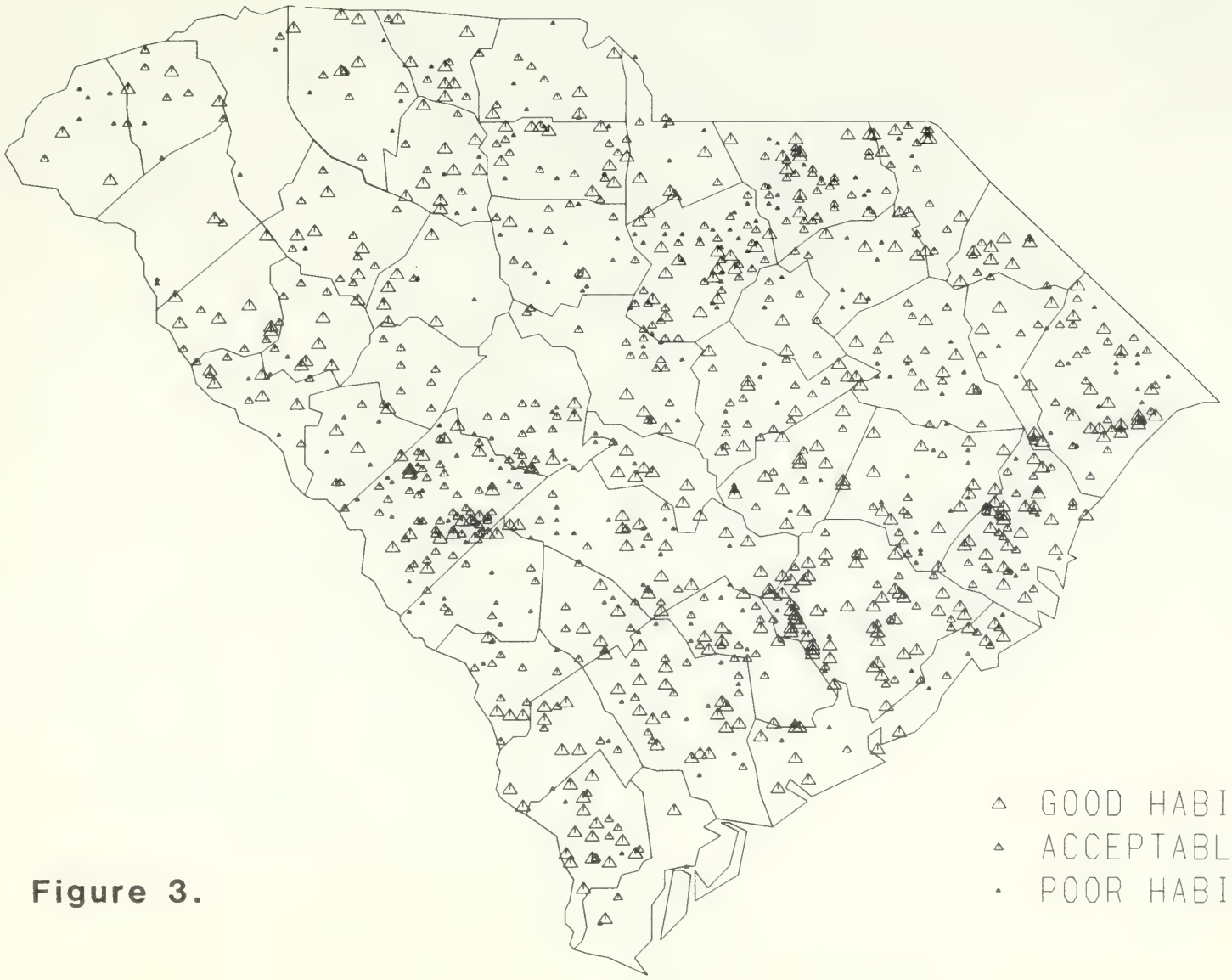
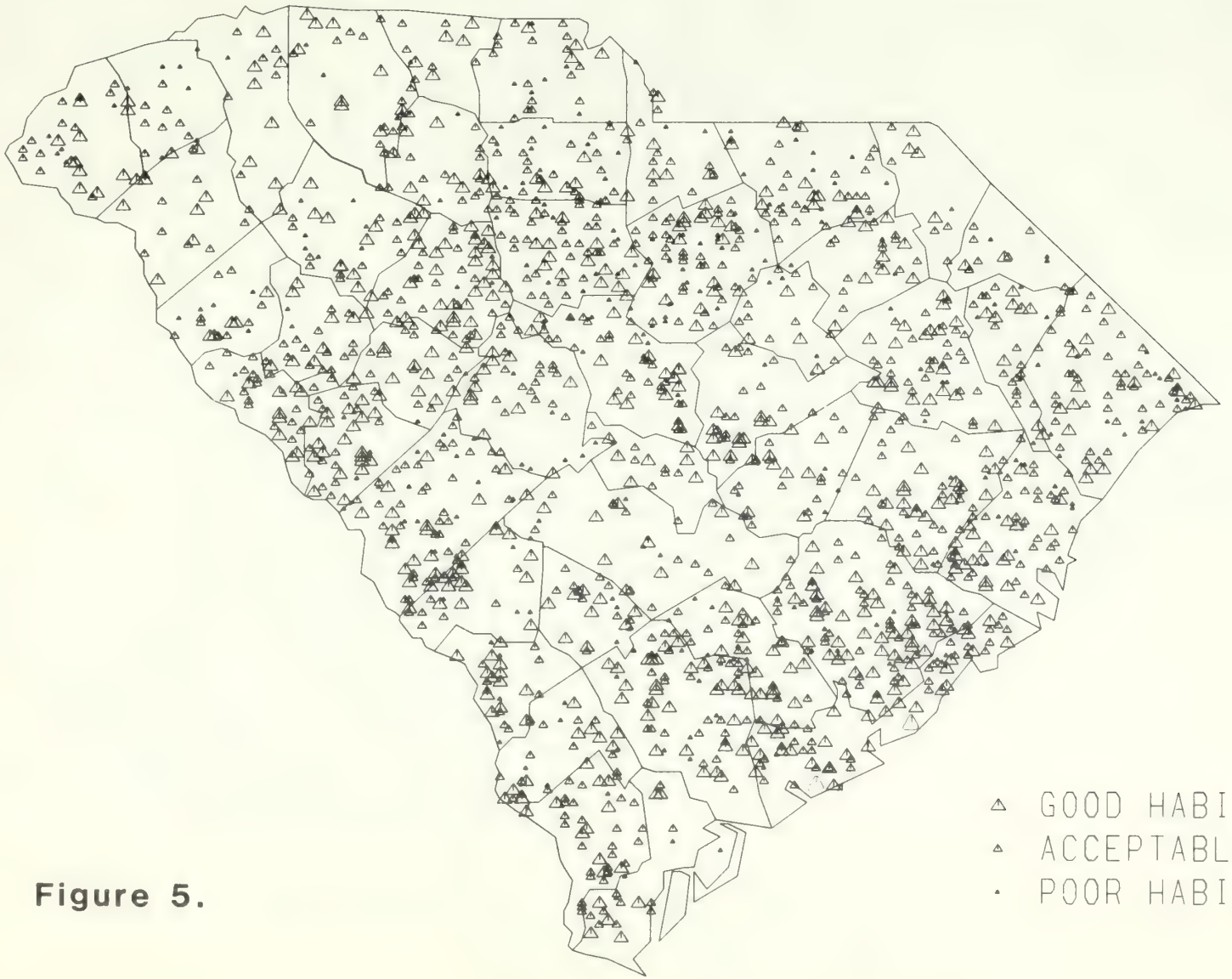


Figure 3.

DISTRIBUTION OF SUITABLE
WOOD THRUSH HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

Figure 4.

DISTRIBUTION OF SUITABLE
PINE WARBLER HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978



△ GOOD HABITAT
△ ACCEPTABLE HABITAT
· POOR HABITAT

Figure 5.

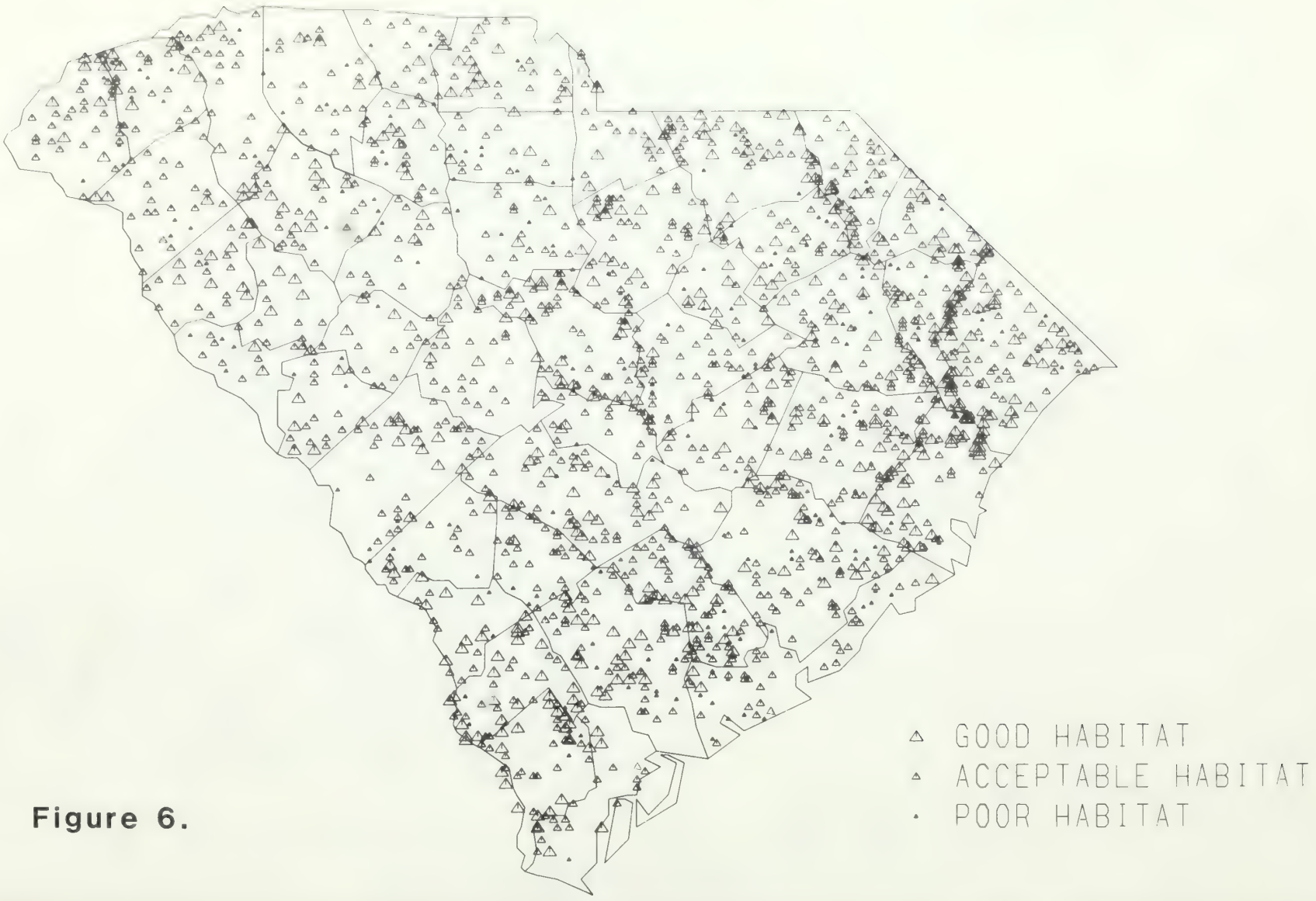

DISTRIBUTION OF SUITABLE
RED-EYED VIREO HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978
GOOD HABITAT
ACCEPTABLE HABITAT
POOR HABITAT

Figure 6.

DISTRIBUTION OF SUITABLE
PILEATED WOODPECKER HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

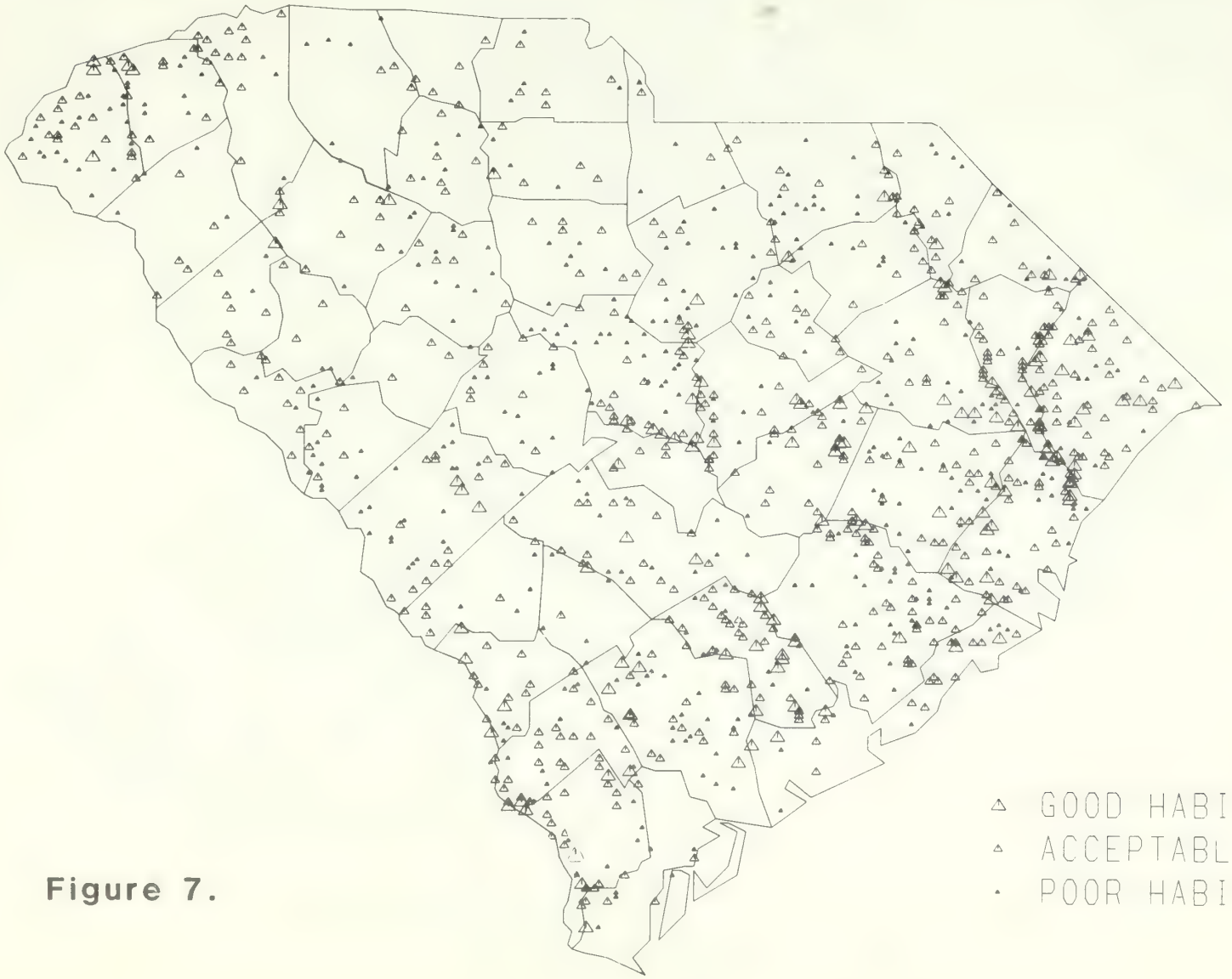


Figure 7.

DISTRIBUTION OF SUITABLE
DOWNY WOODPECKER HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

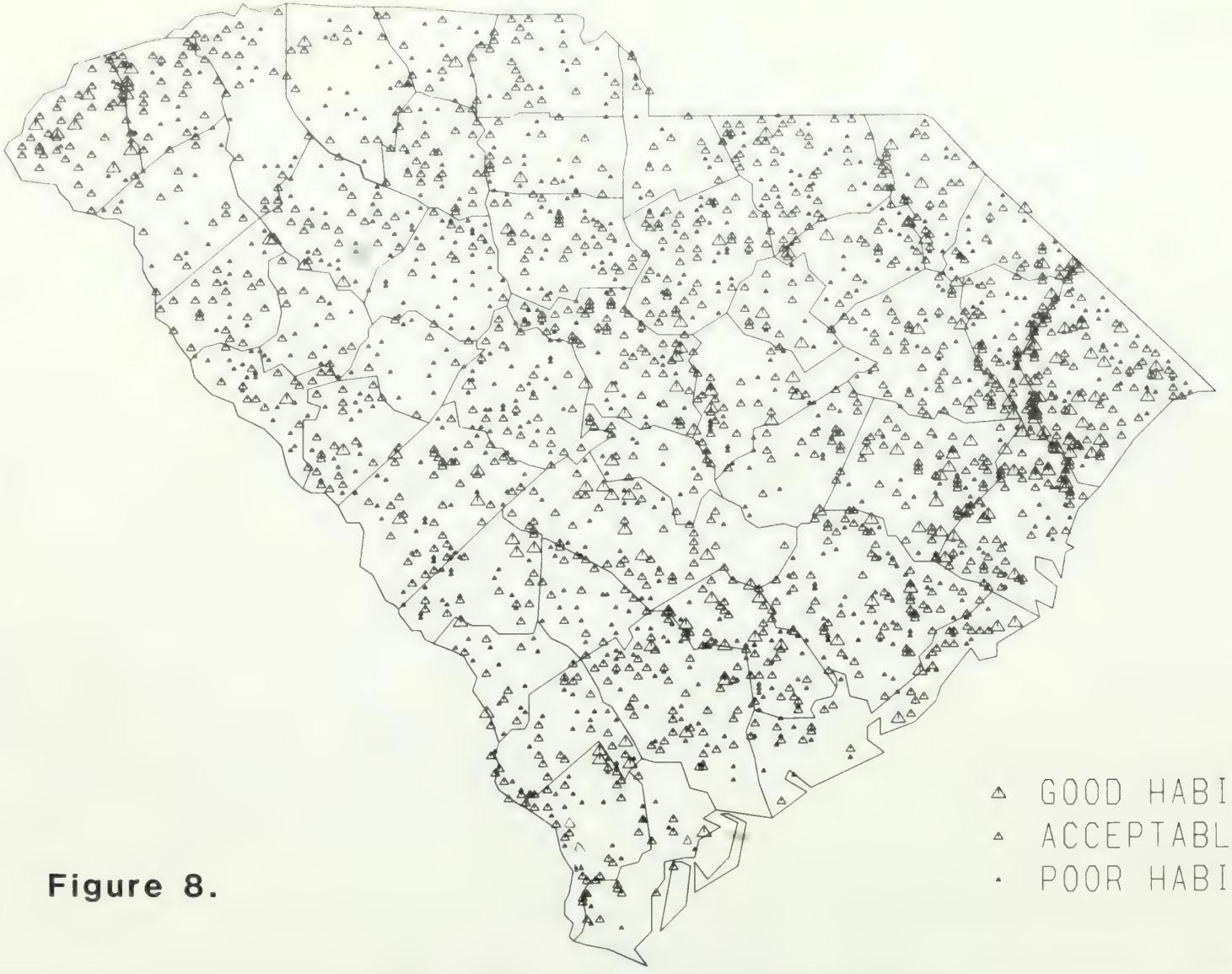


Figure 8.

DISTRIBUTION OF SUITABLE
BROWN-HEADED NUTHATCH HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

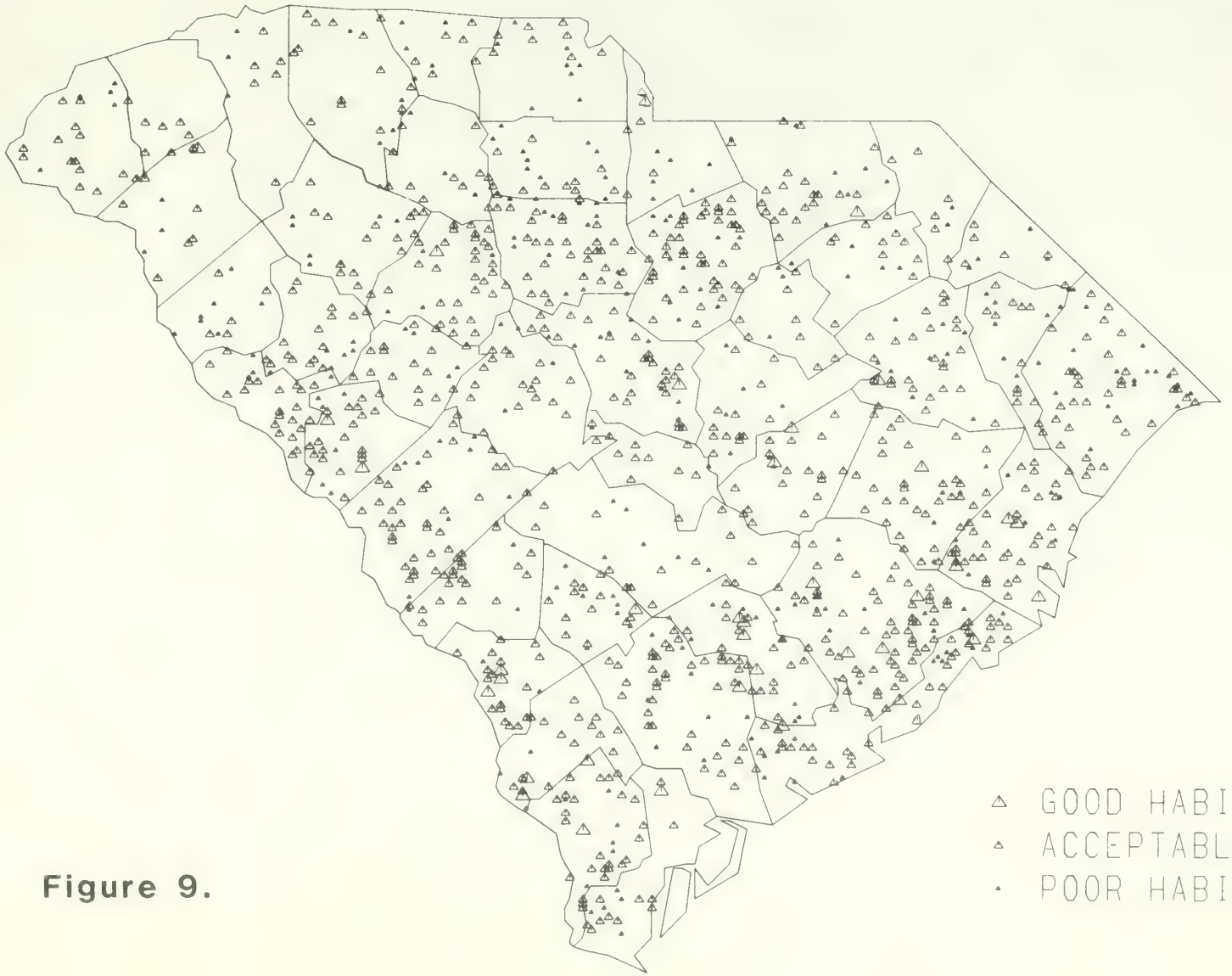


Figure 9.

DISTRIBUTION OF SUITABLE
PROTHONOTARY WARBLER HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

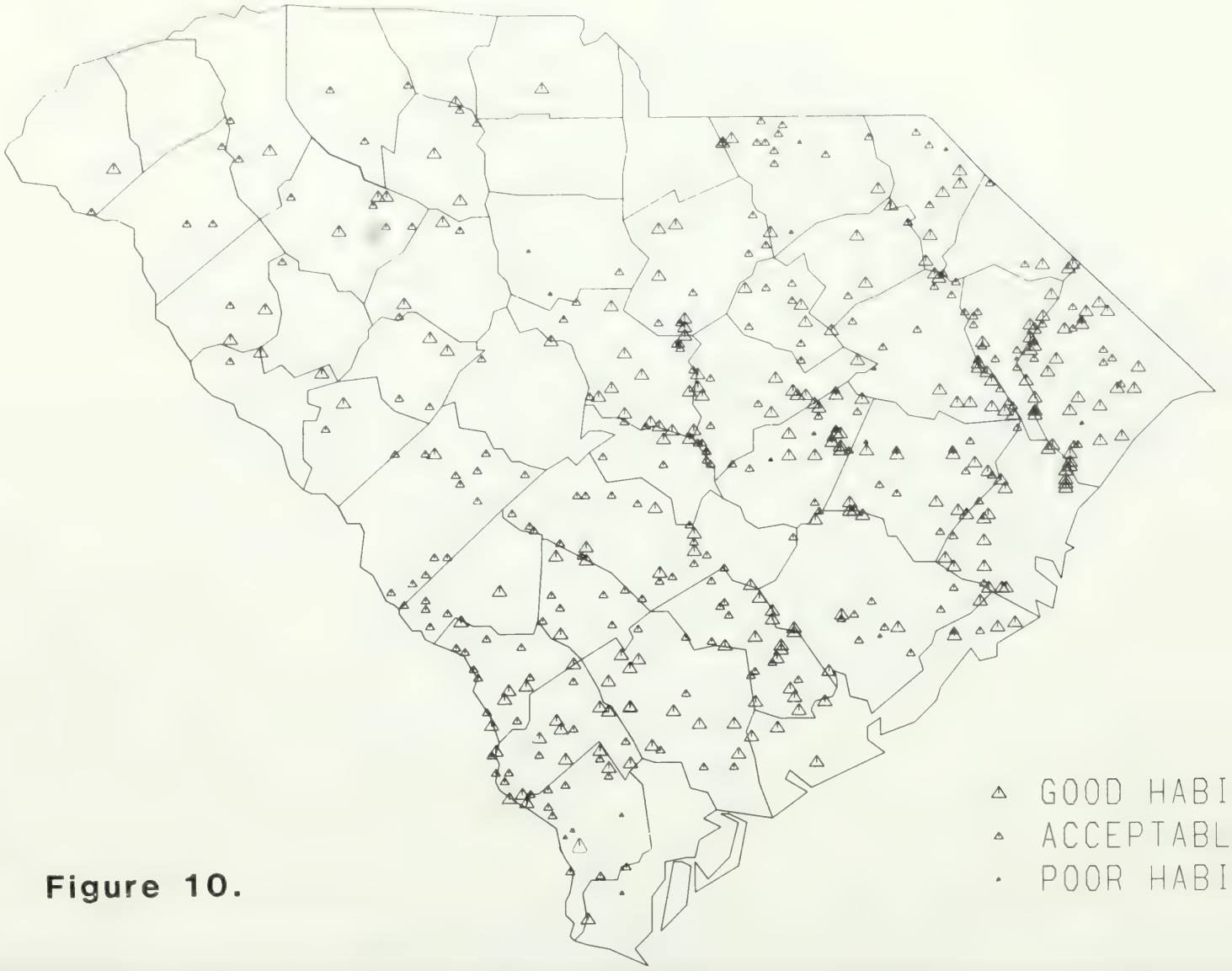


Figure 10.

DISTRIBUTION OF SUITABLE
EASTERN BLUEBIRD HABITAT
BY SUITABILITY CLASS, SOUTH CAROLINA, 1978

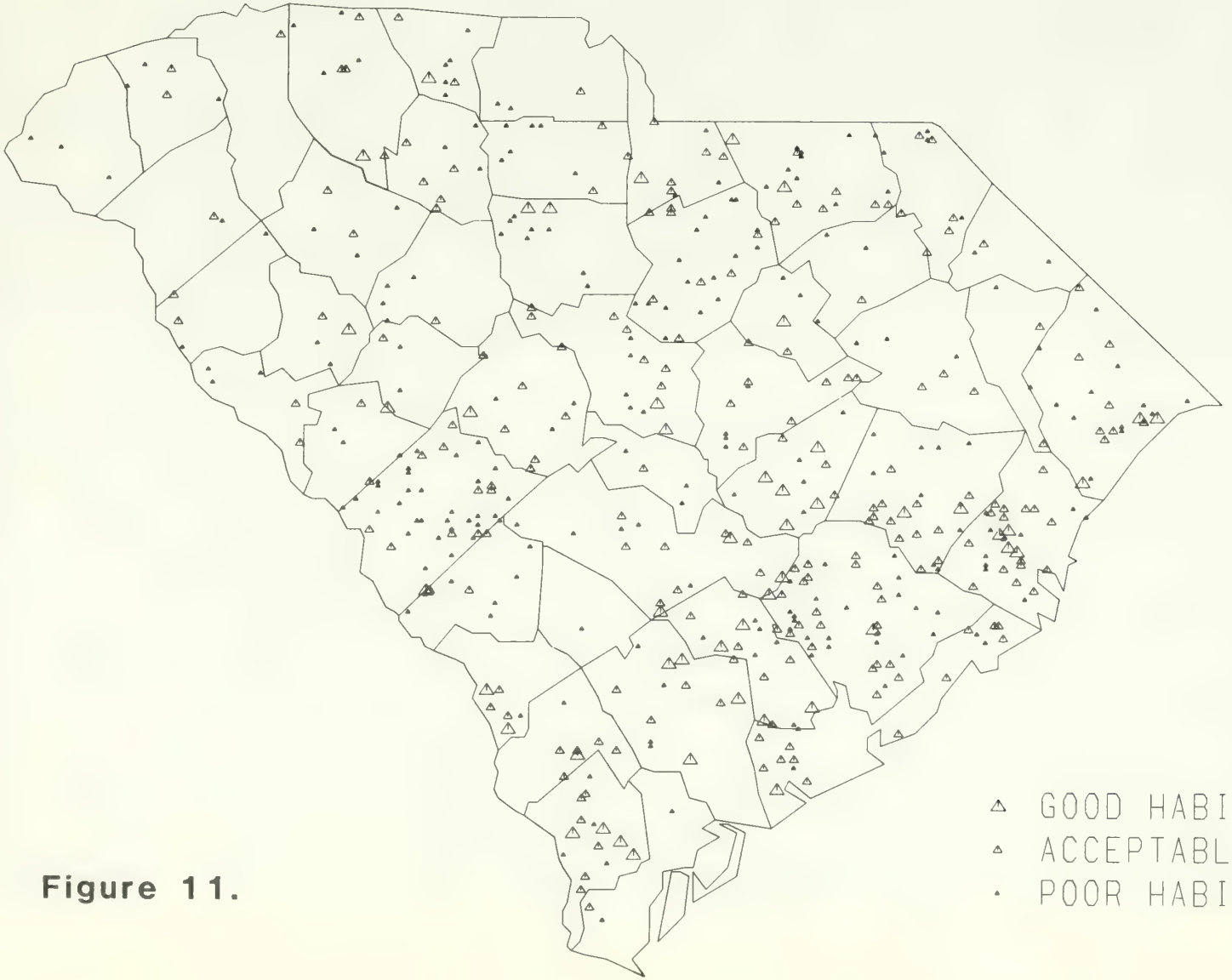


Figure 11.

The ownership of commercial forest land is an important factor in assessing the nontimber resource, as it has been for timber assessments for decades. Varying levels of management between the ownership groups result in differences in wildlife habitat as well as in timber characteristics. The physiography of the forest lands controlled by each ownership group can also affect the kinds and amount of wildlife habitat. Many of these differences show up when we look at the distribution of suitable nongame bird habitat by ownership class (table 3). The first column shows the percentage of all commercial forests that are owned by each ownership group. These percentages are used for comparison with similar percentages for suitable habitat for each of the bird species.

National Forests in South Carolina comprise only 4.6 percent of the commercial forest land (Sheffield 1979). These lands provide a higher than average percentage of suitable habitat for the pileated woodpecker, brown-headed nuthatch, pine warbler, and downy woodpecker; however, they provide considerably less than 4.6 percent of the suitable habitat for the prairie warbler, eastern bluebird, and prothonotary warbler. National Forests have a higher proportion of pine forest types, older stands, and upland physiographic classes than does the State as a whole (Sheffield 1979), which accounts for many of these differences. Forest lands controlled by other public agencies tend to be most favorable for pine stand dwellers (the pine warbler and the brown-headed nuthatch) and least favorable for those birds restricted to hardwood types (red-eyed vireo).

Comparison of the commercial forest and habitat percentages for forest industry lands reveals several differences. Forest industries control 18.6 percent of the commercial forests but provide 25 percent of the prairie warbler habitat, 29.1 percent of the eastern bluebird habitat, and 22.8 percent of the prothonotary warbler habitat. In contrast, only 13.3 percent of the red-eyed vireo habitat is located on forest industry lands. These findings probably result from the large acreage of industry land in young-age classes and pine forest types. Almost 39 percent of the total acreage classified as deep swamps in South Carolina is owned by forest industries, accounting for the abundant prothonotary warbler habitat. The forest industry percentage for the eastern bluebird habitats may be somewhat inflated relative to the other ownerships because the presence of cavities and snags was not used as a requirement. The intensive management practiced by forest industries often eliminates these nesting sources. Adequate data for cavities and snags on cutover forest lands will be available in subsequent inventories.

The two private groups, farmer and miscellaneous private, represent an intermediate management level between the two extremes of National Forests and forest industry. As a result, few major differences appear between the percentage of commercial forest land and suitable nongame bird habitat.

The relative quality of the habitat classified as suitable for each ownership is presented in table 4. The quality ranking for each species and ownership was calculated by summing all the numerical ranking codes for each species and dividing by the total number of suitable plots for that species and ownership. This calculation results in a code ranging from 1.0 to 3.0 and represents the average quality of only the suitable habitat, regardless of the total acreage involved. An average quality for each species across all owners provides a basis for comparison.

The differences between the ownership groups

Table 3.—Distribution of commercial forest land, by ownership class, and of suitable nongame bird habitat, by ownership class and species, South Carolina, 1978

Ownership class	All commercial forests	Species[1]								
		PRWA	WOTH	PINW	REVI	PIWO	DOWO	BRNU	PROW	EABL
	Percent									
National Forest	4.6	2.8	5.3	6.5	4.3	8.4	5.8	7.6	3.4	3.0
Other public	4.1	3.6	3.2	4.7	2.5	3.8	3.4	5.3	3.5	3.6
Forest industry[2]	18.6	25.0	15.6	17.1	13.3	16.7	14.5	16.7	22.8	29.1
Farmer	36.0	33.4	37.0	34.1	42.1	33.4	37.8	32.5	33.9	30.1
Miscellaneous private	36.7	35.2	38.9	37.6	37.8	37.7	38.5	37.9	36.4	34.2

[1] Symbols for the species are given in table 1.
[2] Includes lands under long-term lease.

Table 4.—Average ranking of suitable habitat, by ownership class and species, South Carolina, 1978

Ownership class	Species[1]								
	PRWA	WOTH	PINW	REVI	PIWO	DOWO	BRNU	PROW	EABL
National Forest	2.4	1.8	2.3	2.0	1.7	1.7	1.9	2.4	1.6
Other public	1.9	1.7	2.3	2.0	1.6	1.6	1.9	2.2	1.6
Forest industry[2]	2.4	1.7	2.2	2.3	2.0	1.8	1.8	2.6	1.8
Farmer	2.0	1.8	2.1	2.1	1.6	1.7	1.7	2.3	1.5
Miscellaneous private	2.1	1.8	2.2	2.2	1.8	1.7	1.8	2.5	1.5
Average, all owners	2.1	1.7	2.2	2.1	1.7	1.7	1.8	2.4	1.6

[1]Symbols for the species are given in table 1.
[2]Includes lands under long-term lease.

are not as pronounced for the quality of suitable habitat as those for the distribution because the magnitude of the suitable acreage is not a factor. There are differences, however significant, for some of the species.

Since the rankings in table 4 did not account for the acreage of suitable habitat for each species, another ranking was calculated to depict the overall suitability for each species on lands controlled by each ownership group (table 5). This ranking was calculated by summing all numerical ranking codes, by species and ownership, and dividing by the total number of plots on forest lands held by each owner group. This species ranking code may range from 0.0 to 3.0. An overall ownership ranking is shown in the first column.

National Forests have the highest overall ranking, resulting from higher than average species rankings for the pine warbler, pileated woodpecker, downy woodpecker, and brown-headed nuthatch. The other ownership rankings cluster around the overall average. By individual species, however, several differences become apparent. Forest lands controlled by other public agencies have higher than average species rankings for the pine warbler and brown-headed nuthatch and lower than average for the red-eyed vireo. Forest lands owned or leased by forest industries are better than average for the prairie warbler and the eastern bluebird. Few significant departures from the species averages are indicated for farmers and miscellaneous private landowners. Red-eyed vireo habitat is slightly better than average on forest lands owned by farmers.

Table 5.—Average nongame bird habitat suitability ranking, by ownership class and species, South Carolina, 1978

Ownership class	Owner ranking[1]	Species[2]								
		PRWA	WOTH	PINW	REVI	PIWO	DOWO	BRNU	PROW	EABL
National Forest	6.5	0.4	0.9	1.4	0.8	0.8	1.1	0.9	0.2	0.1
Other public	5.3	.5	.7	1.2	.6	.4	.8	.8	.2	.2
Forest industry[3]	5.6	.8	.7	.9	.8	.5	.8	.5	.4	.3
Farmer	5.4	.5	.9	.8	1.1	.4	.9	.5	.2	.2
Miscellaneous private	5.7	.5	.9	.9	1.0	.5	.9	.5	.3	.2
Average, all owners	5.6	.5	.8	.9	.9	.5	.9	.5	.3	.2

[1]Individual species' rankings may not add to the owner ranking because of rounding.
[2]Symbols for the species are given in table 1.
[3]Includes lands under long-term lease.

DISCUSSION

This study demonstrates that the habitat data and some basic techniques needed to evaluate large forested areas, in terms of their suitability for nongame bird breeding habitat (and the habitat of other nongame and game species), are now available. The results of the evaluations for the nine species seem reasonable, based on the general habitat and population descriptions found in the literature and used to formulate criteria. Research results are needed to replace the subjective criteria used in this evaluation. Field validation efforts are also needed to relate species occurrence and abundance to the projected rankings for each species. Once these two steps are accomplished, the evaluation process presented should prove to be a valuable tool.

The habitat evaluation techniques can be used to evaluate the habitat of a single species of interest or of entire avian communities. If quantified habitat guidelines for a large and diverse group of nongame birds can be assembled, then the forests in the Southeast can be evaluated for these avian communities by selecting several representative or indicator species to fit into each of the habitat groups. Several species are needed in each group to account for the variability among species occupying the same habitat. The results of the habitat evaluations for the nine nongame birds suggest that the species needed for evaluation are those most sensitive to habitat alteration and most restrictive in their selection of breeding habitat.

Estimates of the extent, distribution, and quality of nongame bird breeding habitat, such as that presented in this Paper, should make regional land management planning for nongame birds more feasible. A potentially more valuable asset of the system is that of monitoring the above habitat attributes over time. The RRE multiresource inventories are periodic, returning to each state in the Southeast about every 10 years. The trend information obtained from these reevaluations should prove to be essential input into the decisionmaking process for nongame bird management. The trends established can be related to changes in species composition, age structure, distribution, or management of the forest lands. Armed with this information, managers and policymakers can take steps to alleviate problems, prevent them from developing, and to better coordinate traditional forest management with nongame bird management.

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KEYWORDS: Wildlife habitat evaluation, multiple use, habitat parameters.

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Insecticides for Preventing Insect-Caused Mortality of Paraquat-Treated Slash Pines

by Edward P. Merkel and Edgar W. Clark

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March 1981
Southeastern Forest Experiment Station
Asheville, North Carolina

Insecticides for Preventing Insect-Caused Mortality of Paraquat-Treated Slash Pines

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ABSTRACT.—One- and two-percent concentrations of lindane, carbaryl, chlorpyrifos, and chlorpyrifos-methyl were tested for their efficacy in reducing or preventing bark beetle and wood borer attacks in north Florida slash pine stands that had been treated with paraquat. Results from a series of five field experiments showed that the cumulative mortality of trees unprotected by insecticides 1 year after the indicated month of paraquat application was 63 percent (June 1976), 15 percent (November 1976), 13 percent (February 1977), 83 percent (April 1977), and 40 percent (June 1977). Lindane reduced tree mortality by 50 to 100 percent whereas the other insecticides produced erratic results among experiments. Results also indicate that the season of paraquat treatment is correlated with insect infestation, tree mortality, and subsequent efficacy of insecticides. Recommendations are made for combining pest management procedures with lightwood production techniques that will result in the highest oleoresin yields.

Keywords: Lightwood, bark beetles, wood borers, lindane, carbaryl, chlorpyrifos, chlorpyrifos-methyl.

Pines treated with the herbicide Paraquat® (1, 1'dimethyl 4, 4' -bipyridylium dichloride) to induce resin soaking of the wood are placed under physiological stress that, in conjunction with the resinosis, strongly induces attacks by bark beetles (*Dendroctonus terebrans* (Oliv.), *Ips grandicollis* (Eichh.), *I. avulsus* (Eichh.), *I. calligraphus* (Germ.)), wood-boring beetles (*Monochamus titillator* (F.), *Acanthocinus nodosus* (F.), *Xylotrechus sagittatus* (Germ.), and possibly other species), and other associated insects such as ambrosia beetles (*Platypus flavicornus* (F.), *Xyleborus ferrugineus* (F.), and *X. saxeseni* (Ratz.)).

Hertel and Williams (1975) and Hertel and others (1977) found that bark beetle attack and subsequent mortality of slash pine trees (*Pinus elliottii* Engelm. var. *elliottii*) increased following paraquat application when paraquat concentration was increased from 0.5 to 8 percent, wound size was increased from one-sixth to two-thirds of the tree circumference, the ax-chop method of wounding was used instead of the bark-chip method, and paraquat was applied in April and July. Several researchers have verified the first three observations, which can be generalized to state that insect attack and tree mortality increase directly with the quantity and concentration of paraquat and the size and severity of the wound. Insecticide formulations of 0.5 and 1-percent water emulsions of BHC (benzene hexachloride) (Hertel and Williams 1975; Moore 1977) and 1-percent water emulsions of lindane (Hertel and others 1977) were shown to be effective in reducing tree mortality following paraquat treatments even when high paraquat concentrations were applied to severely wounded trees. They also found that chlorpyrifos and chlorpyrifos-methyl were promising insecticides for protecting paraquat-treated trees from insect attack.

Reported here are further evaluations of the efficacy of lindane and alternative insecticides in preventing tree losses due to bark beetle infestation in paraquat-treated stands. Additional information on the effect of season of paraquat applica-

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tion on tree mortality and resin and turpentine extractive yields is also presented. Studies were conducted in three plantations and in a natural stand of slash pine on the Olustee Experimental Forest, Baker County, Florida, from June 1976 to June 1979.

METHODS

Five field experiments were established chronologically, by date of paraquat application:

Application date	*Slash pine stand*	*Average d.b.h.* (cm)
June 1-3, 1976	Plantation	16.8
November 10, 1976	Natural	21.3
February 22-25, 1977	Plantation	17.8
April 20-22, 1977	Plantation	20.4
June 14-17, 1977	Plantation*	16.8

*Same as June 1976

Design of experiments was completely randomized, with 20 or 30 trees per treatment. In the area where these tests were conducted, there was a severe drought between June 1976 and June 1977, with a cumulative rainfall deficit of 36.6 cm below normal.

Trees, including check trees not sprayed with insecticides, received a horizontal bark-streak wound 2.5 cm wide by 1/3 of the tree circumference at 0.5 m above ground line with a motorized chipping tool (Clements and McReynolds 1977). A 4-percent aqueous paraquat solution was applied with a plastic squeeze bottle immediately after wounding. A single paraquat application was used in the experiments of June and November 1976 and February and April 1977. For the June 1977 experiment, the same trees that had been treated 1 year earlier but had survived were given a second paraquat application to the sides of the trees opposite the June 1976 wounds.

After the paraquat application, the following insecticides were applied at 1 and 2 percent (active ingredients):

Lindane E-20 (gamma 1,2,3,4,5,6-hexachlorocyclohexane) (Southern Mill Creek Products Co., Tampa, Fla.)

Chlorpyrifos (0.0-diethyl 0-(3,5,6-trichloro-2-pyridyl) phosphorothioate) (Dow Chemical Co., Atlanta, Ga.)

Chlorpyrifos-methyl (0,0-dimethyl 0-(3,5,6-trichloro-2-pyridyl) phosphorothioate) (Dow Chemical Co., Atlanta, Ga.)

Carbaryl (1-naphthyl methylcarbamate) (Union Carbide Corp., Columbia, S.C.)

Lindane was included as a standard of comparison because it and BHC, a mixture of isomers containing lindane, have been the principal insecticides used for bark beetle control for the past 30 years. All insecticides were not represented in every experiment because chlorpyifos-methyl and carbaryl were not always available when each experiment was installed. As a result, the efficacy of these two chemicals could not be compared in all tests.

Insecticides were applied to the tree trunks within 48 hours after paraquat treatment by means of a hand sprayer with the exception of the late-winter test in which half of the trees were sprayed immediately after paraquat treatment and the remaining half were sprayed 1 month later.

Most insecticides were applied to a height of 3 m above ground line to runoff, except as noted in table 3, where some sprays were applied only to a height of 1 m. The June 1977 trees, which survived 12 months after the start of the June 1976 test, were resprayed with the same insecticide but not necessarily at the same concentration nor to the same height as before.

The efficacy of these insecticides was determined by the cumulative percent tree mortality 12 months after paraquat application. Only the check trees were used to evaluate the seasonal impact of insects following paraquat application. To identify the insects and the rate of tree mortality, two to four observations per month were made in the June and November 1976 tests for the first 6 months and one observation each month thereafter. In subsequent experiments, four observations per month were made for the first 3 months, two observations per month for the next 3 months, and two observations every other month thereafter. The identity of attacking *Ips* pine engraver beetles, the black turpentine beetle, ambrosia beetles, and cerambycid wood borers was based on the presence of pitch tubes, boring dust, and niches for egg-laying.

To determine the oleoresin production of paraquat-treated trees during the winter, three replicates of 15 paraquat-treated trees each in the early-winter experiment and a similar number of adjacent untreated trees were selected randomly and felled 22 months after establishment of the November 1976 test. Two consecutive bolts, each 2 m long, were cut from each tree commencing 15 cm below the wound. Disks of wood, 2.5 cm thick, were cut every 50 cm from the remainder of each tree trunk (bolt 3) until the diameter of 10 cm was reached. These disks were packaged in plastic bags, by bolt origin, and maintained at −5°C until analyzed. For analysis, the disks from each bolt were ground, pooled, and duplicate samples of 10 g and 50 g each withdrawn for resin acid and turpentine analyses, respectively, as described by Munson (1979) and Shepard (1975).

RESULTS AND DISCUSSION

Effects of Season of Paraquat Application on Tree Mortality

Mortality of trees without insecticides was much higher 1 year after April and June paraquat applications than after November and February applications (table 1).

It should be noted that 11 of the 20 check trees used in the June 1977 experiment were surviving check trees from the June 1976 study. Consequently, 9 trees that had been sprayed with insecticide 1 year earlier had to be used to make 20 check trees for the June 1977 experiment (table 1). Of the 40-percent tree mortality occurring 1 year after the second paraquat application (June 1977), 62 percent was of unsprayed check trees that had survived the June 1976 experiment. That is, of the original check trees used in June 1976, 63 percent died the first year and 17 percent died during the year after the June 1977 paraquat application, bringing the 2-year cumulative mortality to 80 percent of the original unsprayed trees.

greatest following April treatments and decreased in the order: April > June > February = November. Although the seasonal trends in tree mortality between these sets of data were comparable, it should be noted that Hertel and others (1977) used twice the paraquat concentration, i.e., 8 percent; consequently, total cumulative tree mortality was much higher than that summarized in table 1.

Since bark beetles and wood borers are inactive in north Florida from November through February, it is not surprising that tree mortality was low following the November and February paraquat applications.

Conversely, the devastating tree mortality following paraquat applications in April may have been the result of a critical physiological stress on the trees at a time when spring growth flush was most active. Audus (1964) found that the activity of herbicides generally increases with increasing plant growth.

We conclude that whenever it is feasible, paraquat applications should be made during the coldest months of the year to minimize insect-caused tree mortality. Furthermore, if lower paraquat concentrations, e.g., 2 to 4 percent, are used during the winter, insecticide application could be eliminated.

Table 1.—Cumulative mortality of slash pines, not sprayed with insecticides, at intervals following paraquat application[a]

Paraquat applied (date)	No. of trees	Cumulative tree mortality after:				
		1 month	3 months	6 months	9 months	12 months
		Percent				
June 1976	30	0	13	33	50	63
November 1976	20	0	0	0	0	15
February 1977	30	0	0	0	7	13
April 1977	30	0	3	60	77	83
June 1977	20	0	0	9	27	40

[a]4-percent aqueous paraquat on a 2.5-cm by 1/3-circumference bark-streak wound.

Unsprayed trees treated with paraquat during June 1976 and April 1977 were attacked by bark beetles and wood borers and began to die within 3 months (table 1), and the rates of tree mortality nearly reached the maximum mortality attained 9 months after these treatments. Insect attack and tree mortality were delayed from 4 to 5 months after the June 1977 paraquat application (table 1) despite the second paraquat application. Tree mortality following November and February paraquat applications occurred 7 to 10 months after treatment and at a much lower rate than in the warm season.

Hertel and others (1977) conducted experiments in Florida with planted slash pine comparable in age and size to those reported here and found that tree mortality 1 year after paraquat application was

Effects of Winter Paraquat Application on Lightwood Extractives Yields

Analyses of resin acid and turpentine yields (Shepard 1975) from randomly selected trees were made 22 months after initiation of the November 1976 experiment. Yields were significantly higher for paraquat-treated than for untreated trees (table 2). The yields obtained in this small test compare favorably with yields reported by Roberts (1973) and Munson (1979) for slash pines treated during warm weather on the Olustee Experimental Forest.

Table 2—Extractives from slash pine treated with paraquat on November 1976 and analyzed 22 months later

Extractive	Treated bolts[a,b]			Untreated bolts[b]		
	1	2	3	1	2	3
	kg/m^3					
Resin acids	39.40 ± 3.04	15.06 ± 0.48	9.61 ± 10.89	9.93 ± 0.48	8.97 ± 0.48	10.09 ± 1.12
Turpentine	11.05 ± 0.80	3.20 ± 0.32	1.44 ± 0.16	1.12 ± 0.16	1.12 ± 0.16	1.76 ± 0.32
Water	512.58 ± 4.64	629.99 ± 23.71	739.39 ± 19.22	619.42 ± 13.29	680.76 ± 12.17	723.53 ± 9.61

[a]4-percent aqueous paraquat was sprayed on a bark wound 2.5 cm by 1.3 the circumference of the tree cut 0.5 m above the ground.

[b]Bolts 1 and 2 were 2 m long, the lower cut of bolt 1 beginning 15 cm below the paraquat wound. Each date is the mean and standard error of three replicates of 15 trees each, i.e., a total of 90 trees.

However, winter applications of paraquat cannot be recommended as a standard practice until it is thoroughly demonstrated that economically adequate amounts of lightwood extractives will result.

Efficacy of Insecticides to Prevent Tree Mortality

The cumulative tree mortality 12 months after establishment of each experiment, for all insecticide formulations tested, is summarized in table 3. Results of each experiment are as follows:

June 1976—All formulations of lindane, chlorpyrifos, and chlorpyrifos-methyl significantly reduced tree mortality at the end of 1 year, compared with the unsprayed check.

November 1976—No tree mortality occurred in the 2-percent carbaryl-molasses and lindane treatments 1 year after paraquat application. These insecticides reduced tree mortality significantly over the 2-percent carbaryl, chlorpyrifos, and check treatments.

February 1977—Twelve-month cumulative tree mortality was not significantly different between trees that had been sprayed immediately after paraquat application and those sprayed 1 month after paraquat application, hence data for these two spray dates were combined for final analysis of insecticide effectiveness. No insecticide formulation in this test reduced tree mortality significantly below that of the check.

April 1977—The three lindane treatments were the only ones that significantly reduced tree mortality below the check, and 1-percent lindane sprayed to a height of 3 m did not reduce tree mortality significantly more than the same formulation sprayed to a height of only 1 m.

June 1977—All insecticide treatments except 1-percent chlorpyrifos-methyl (3-m spray height) significantly reduced tree mortality, compared with the check; however, differences among insecticide treatments were not significant.

Although carbaryl, chlorpyrifos, and chlorpyrifos-methyl showed some promise as possible alternative chemicals to lindane, results were too erratic among tests to draw a strong conclusion as to their effectiveness. Examination of the 3- and 6-month cumulative tree mortality data suggests that tree protection afforded by these three possible alternatives began to fail about 3 months after application.

Consequently, further field tests with these compounds, particularly in combination with adjuvants to increase their residual toxicity, are warranted. In addition, more efficient sprayers,

Table 3.—Total slash pine tree mortality 12 months after treatment

Insecticide treatment	Spray height (meters)	Tree mortality according to dates of treatment				
		June 1976	Nov. 1976	Feb. 1977	April 1977	June 1977
		Percent				
1% Lindane	1			7a	53ab	5ab
1% Lindane	3	10b	0a	7a	40a	0a
2% Lindane	1					5ab
2% Lindane	3	0a	0a	3a	43ab	5ab
1% Chlorpyrifos-methyl	1					15bc
1% Chlorpyrifos-methyl	3	0a		7a	70bcd	5ab
2% Chlorpyrifos-methyl	1					5ab
2% Chlorpyrifos-methyl	3	0a		20a	63abc	
1% Chlorpyrifos	1					10ab
1% Chlorpyrifos	3	0a	20 b	17a	87 cd	10ab
2% Chlorpyrifos	1					5ab
2% Chlorpyrifos	3	3ab	5ab	17a	90 d	
1% Carbaryl-molasses	3		10ab	13a	77 cd	
2% Carbaryl-molasses	3		0a	3a	67abc	
Check-paraquat only		63 c	15 b	13a	83 cd	40 c

Any two percentages followed by the same letter, within each column, are not significantly different at the 5-percent probability level by Duncan's new multiple range test.

such as portable mist blowers, should be investigated in order to apply insecticides to the bark more quickly and to optimize the quantity applied. The present technique of spraying to runoff is wasteful. Research on improvement of spray formulations and spray equipment could increase the efficacy of insecticides, reduce costs of application, and generally reduce hazards to the insecticide applicator and the environment.

Another opportunity of increasing insecticide effectiveness was demonstrated by the February 1977 experiment in which one-half of the insecticide treatments were delayed 1 month after paraquat application. A delayed treatment would be particularly advantageous when using insecticides with a relatively short-residual toxicity. For example, if insecticide applications in stands treated with paraquat in the winter, particularly late winter, could be delayed until the onset of warmer weather and increased bark beetle activity, the period of time that residues must remain effective for tree protection would be decreased and the period of protection by low-residual insecticides might be used more efficiently.

Threat of Bark Beetle Spread from Paraquat-Treated Stands

Forest managers who contemplate a large-scale application of paraquat might justifiably question whether paraquat-treated trees would serve as reservoirs for bark beetle population buildup and subsequent spread to adjoining untreated stands. During the 3 years our tests were conducted, and in other paraquat research plots involving thousands of treated trees on the Olustee Experimental Forest, no untreated trees were attacked by bark beetles in or adjoining the paraquat-treated plots despite drought from June 1976 to June 1977.

Opportunities for Insect Pest Management in Lightwood Operations

Since the first report of inducing lightwood (Roberts 1973), tree losses caused by bark beetle infestation of paraquat-treated pines appeared to be an insurmountable problem. However, in the 6 years since research was initiated to develop lightwood technology, entomologists and other scientists have obtained sufficient knowledge to enable us to conceive of an integrated pest management system for future commercial lightwood operations.

The following procedures, suggested by this and other research, might be incorporated in a commercial lightwood operation to minimize insect-caused tree losses while maintaining economic levels of lightwood extractives:

(1) *Reduce the paraquat concentration as low as possible consistent with the recommended method of application.* Carefully read the labeled uses of Ortho Paraquat CL® (EPA Reg. No. 239-2186-AA; Chevron Chemical Co., Richmond, Calif.), which recommend concentrations ranging from 0.2 to 5 percent.

(2) *Use only method and number of paraquat applications recommended on label.* Several methods of application are recommended on the Ortho Paraquat CL® label, e.g., 2.5 cm by 1/3-cir-

cumference bark streak, bore holes, and Med-e-Jet® injector.

Although insects can attack trees regardless of the method of paraquat application, tree mortality is usually more severe when implements such as ax frills or Jim-Gem® herbicide applicators are used and bark streaks more than 2.5 cm wide and greater than 1/3 bark circumference (Hertel and others 1977; Roberts 1979) are used to expose large areas of xylem and inner bark, which results in excessive oleoresin flow from wounds.

Until further research can demonstrate the economic feasibility and substantial increases of lightwood extractive yields following multiple paraquat applications, such a procedure should be avoided.

(3) *No insecticides required following winter paraquat application.* If paraquat concentrations of 4 percent or less are applied during the winter months in the South, i.e., the interval between the first fall frost and the last spring frost, tree mortality probably will not exceed a total of 15 percent of all treated trees, even when preventive insecticide sprays are not used. With insecticide application, tree losses should be almost negligible. Preliminary research results reported by Moore and others (1979) suggest that insecticide treatments might be eliminated entirely on paraquat-treated loblolly pines in the Piedmont region.

(4) *Insecticide sprays are required following spring, summer, and fall paraquat applications.* A 1-percent lindane water emulsion applied to the basal 1 m of the trees, immediately following paraquat application, can reduce tree losses by 50 to 100 percent. Without the preventive insecticidal spray, tree losses can be expected to range from 40 to 85 percent.

The reader should note that these suggested procedures are based entirely on research conducted in slash pine stands in north Florida and should not be construed as southwide guidelines or recommendations. Nevertheless, these guidelines provide timberland managers with several alternatives for minimizing insect-caused tree losses in slash pine stands treated with paraquat. Further research, southwide, should eventually lead to the integration of other procedures that could virtually eliminate the use of insecticides in lightwood operations.

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Lindane consistently reduced tree mortality from 50 to 100 percent in field tests conducted over a 3-year period. Chlorpyrifos, chlorpyrifos-methyl, and carbaryl showed some promise as alternatives to lindane for preventing bark beetle attacks. Tree mortality was highest following paraquat applications in April and June and lowest following February and November treatments. Recommendations are made for combining pest management procedures with lightwood production techniques to optimize lightwood extractive yields.

KEYWORDS: Lightwood, bark beetles, wood borers, lindane, carbaryl, chlorpyrifos, chlorpyrifos-methyl.

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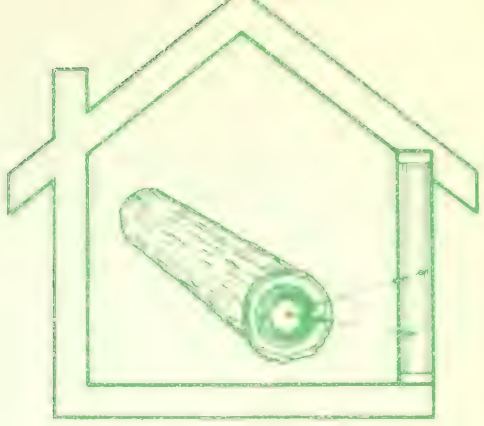

COM-PLY® 19

REPORT

Evaluation of Veneer Yields and Grades from Yellow-Poplar, White Oak, and Sweetgum from the Southeast

COOPERATIVE RESEARCH

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PREFACE

This report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in houses. Research on structural framing is currently limited to COM-PLY studs but will be extended to include larger members such as floor joists.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem and that long-range plans for better use of the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with particleboard and veneer as a way of using not only more of the tree stem, but also of using less desirable trees and a greater variety of tree species than would conventional wood products. The particleboard, which forms a large portion of COM-PLY studs and joists, is made from chipped-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Georgia. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid-wood lumber, suggest performance standards for composite lumber, and provide construction details for incorporating such lumber in houses. Still others will explore the economic feasibility of manufacturing composite lumber and panels, and will estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

Evaluation of Veneer Yields and Grades from Yellow-Poplar, White Oak, and Sweetgum from the Southeast

by
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ABSTRACT.—The dry volume yield and standard grades of veneer are given for yellow-poplar, sweetgum, and white oak by tree diameter and location within the stem. Manufacture of composite structural lumber and panels can effectively utilize available hardwood stands. The lower 26 feet of the stem of trees 16 inches d.b.h. and smaller yield a high proportion of grade C and better veneer that is desirable for COM-PLY lumber, while veneer of all grades can be used for the panels, and the particleboard cores can be made from both forest and mill residues. Although the total veneer yield from hardwoods is generally less than that from loblolly and slash pines, typical stands of mixed southern pine and hardwood timber yield enough veneer to utilize almost 90 percent of the stand volume in the production of COM-PLY products.

Keywords: COM-PLY, lumber, panels, *Liriodendron tulipifera* L., *Liquidambar styraciflua* L., *Quercus* sp.

Forest products are mostly used in residential and commercial construction. Practically all of the wood products that are used in construction are softwoods. This dependence on softwood is based on its availability, ease in nailing, ease of drying, and generally lighter weight than common hardwoods. Projections of future demand for softwood forest products indicate that demand for timber will exceed supply (USDA FS 1973).

Hardwoods predominate in the forests of the United States. Ninety percent of the hardwood forests are found east of the Mississippi River (USDA FS 1978). If future demands for forest products are to be satisfied, some methods must be found for using more of our hardwood. Select hardwood lumber and veneer have always had a ready market for their use in furniture, cabinets, and paneling. For centuries the hardwood forests have been selectively cut so that the more valuable trees are taken, and the cull trees and less desirable species are left. The residual hardwood stands are a major forest management problem. In many cases, the present hardwood stands are a losing proposition: it would cost more to harvest the present stands and prepare them for restocking than could be realized by the sale of their timber.

The COM-PLY approach to the manufacture of composite structural lumber and panels is ideally suited to the efficient use of available hardwood stands. COM-PLY lumber requires about 25 percent of veneer to provide strength and stiffness (fig. 1). The particleboard making up the remaining 75 percent of COM-PLY lumber volume can be made from low-quality forest or manufacturing residues. Composite products minimize the major problems of using hardwoods for lumber such as long drying time, poor dimensional stability, and difficulty in obtaining large sizes and long lengths. Tests of the structural properties of COM-PLY studs made with yellow-poplar, white oak, and sweetgum (McAlister 1979) indicate that COM-PLY lumber made with these species are comparable with COM-PLY lumber made from southern pine (McAlister 1978).

The Southeastern States (Alabama, Georgia, Florida, North Carolina, South Carolina, and Virginia) have large areas of hardwood forests. These forests are extremely diverse, ranging from swamps to mountain ridgetops, and they include dozens of commercially important hardwood species. However, most of the growing-stock volume consists of only a few species: For example, in the mountains and the Piedmont, seven species account for over 50 percent of the total wood volume, of which yellow-poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), and white oak (*Quercus sp.*) account for about 40 percent. Information on these species is needed in order to evaluate the hardwood resource.

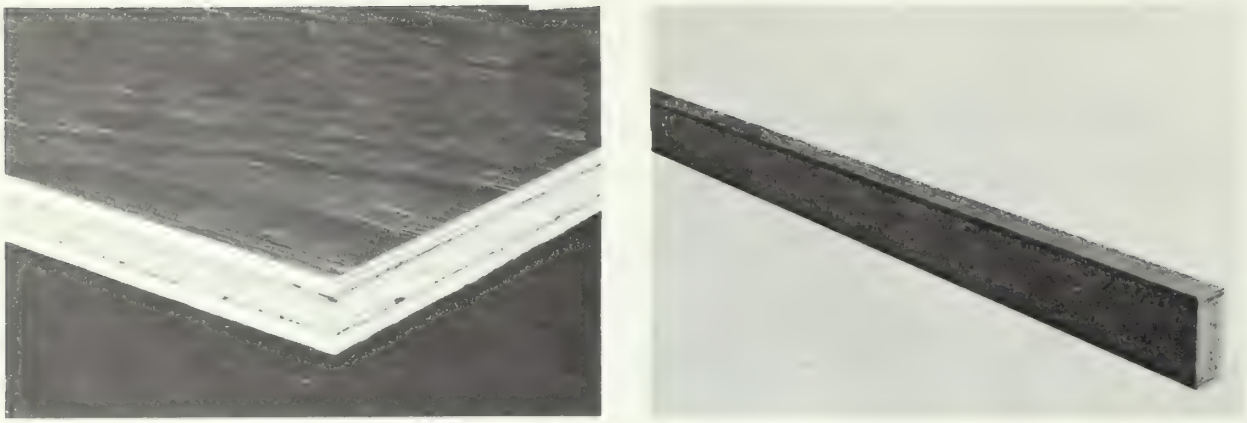

Figure 1.—Construction of a COM-PLY panel (left) and a COM-PLY stud (right).

Previous research on the hardwood veneer resource has been concerned with high-quality face veneers and the veneer for core and crossband stock for paneling and furniture. This study describes the dry cubic footage and grades of veneer that are available from yellow-poplar, sweetgum, and white oak according to tree diameter at breast height (d.b.h.) and location within the stem. Similar to COM-PLY 9, "Yield of Southern Pine Veneers Suitable for Composite Lumber and Panels" (McAlister and Taras 1978), this report can be used along with COM-PLY 9 to study potential yields from mixed hardwood and softwood stands.

PROCEDURES

The trees for this hardwood veneer yield study were selected as part of a total tree (above ground) biomass study (Clark and Phillips, unpublished[1]). Trees from two geographical areas were sampled: yellow-poplar, white oak, and sweetgum from the central Georgia Piedmont (Oconee National Forest); and yellow-poplar and white oak from the southwestern North Carolina mountains (Nantahala National Forest). For each location and species, we selected three trees from each of the six even-inch (12, 14, . . . 20) diameter classes from 12 to 22 inches d.b.h. For example, the 12-inch d.b.h. class includes trees from 11 to 12.9 inches d.b.h. The trees were felled and bucked into veneer-length logs. A veneer block is 8.75 feet long. As far as practical, we cut two and three block-length logs for ease in skidding and hauling. The minimum top diameter was about 8 inches. We cut 1-inch sample disks at each bucking cut. These disks were used to determine specific gravity, bark thickness, growth rate, and moisture content. The logs were individually weighed and then hauled to a cooperating southern pine plywood plant. The logs were cut into veneer blocks 103 to 104 inches long and debarked. We marked each block with the tree and block number of the stem (fig. 2). The end diameters of each block were recorded to the nearest 0.1 inch. All blocks were heated in 180°F (82°C) water for 15 to 16 hours before peeling. The veneer lathe was set to produce 0.167- to 0.170-inch-thick veneer. The peeler core diameter was recorded for each block and averaged about 5.4 inches.

Veneer from individual blocks was color coded with strips of water-soluble dye so that the veneer that was produced could be related to the block from which it was peeled (Schroeder and Clark 1970). Veneer was clipped

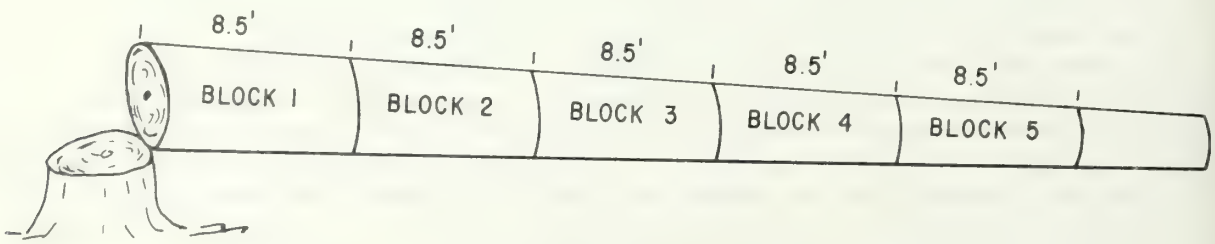

Figure 2.—Diagram of veneer blocks measured on stem.

[1]Data on file Southeast. For. Exp. Stn., For. Sci. Lab., Athens, Ga.

into full sheets, half sheets, and strip according to standard mill practice for softwood veneer-grade defect limitations. Veneer was dried for 12 minutes at 385°F in a commercial steam-heated, jet-type veneer dryer to an average moisture content of less than 6 percent. Veneer was graded after drying as per softwood veneer grades (American Plywood Association 1974). Dry veneer volumes and grade were recorded for veneer 0.160 inch thick and for sheet sizes as follows:

Full sheets — 50 by 102 inches
Half sheets — 26 by 102 inches
Strip — actual width by 102 inches
Fishtail — actual width by 54 inches

All strip and fishtail were graded as C- or D-grade veneer. Actual widths for strip and fishtail ranged between 12 and 25 inches.

RESULTS AND INTERPRETATION

The results of this study represent a wide range of tree diameters from two geographic locations. The main body of the report includes only data by tree-diameter class (table 1) and derived information from the central Georgia Piedmont. Yield tables from the southwestern North Carolina mountains by tree-diameter class are presented in the Appendix. The Appendix also includes yield tables from both areas by veneer-block diameter. The trees from the mountains were generally taller and had more veneer blocks per stem than did those from the Piedmont.

Information in table 1 can be used to estimate the quantity of veneer that can be produced from natural hardwood stands in the Piedmont. Species distribution by diameter class is usually available from timber-cruise data or from forest statistical information published by the U.S. Forest Service as part of their forest survey data.

For example, Cathey (1972) estimates the diameter distribution for oak, sweetgum, and yellow-poplar in diameter classes 12 to 20 inches d.b.h. in central Georgia to be:

d.b.h.	*Percent*
12	49
14	26
16	14
18	7
20	4

Further, the estimated species distribution is 49 percent oak, 37 percent sweetgum, and 14 percent yellow-poplar. Similar calculations can be made for any area and mix of species for which forest survey data are published. These estimates were used to construct table 2, which assumes 100 woods-run trees from a hardwood logging operation in central Georgia.

From table 2, it is evident that, although oak accounts for almost half of the number of trees, only 25 percent of the C and better grade veneer is oak. This means that oak peeling and log residues will make up a large proportion of the total. Because of the high density of oak, it may not be practical to use more than 15 to 20 percent oak in the particleboard furnish to maintain the desired density (37 pounds per cubic foot) of the particleboard core that is used in COM-PLY products.

This typical mix of 100 hardwood trees yields about 375 cubic feet of dry C and better veneer from a total tree volume of 3,000 cubic feet. Notice that the veneer-block volume is 1,770 cubic feet. Thus, logging to a 4-inch diameter inside bark (d.i.b.) top would provide an additional 1,300 cubic feet of green wood in addition to that in the veneer blocks.

We estimate that the 375 cubic feet of dry veneer loses about 10 percent in manufacturing, leaving about 338 cubic feet of veneer in the finished product. The 3,008 cubic feet of green tree volume shrank (12 percent volumetric) to about 2,650 cubic feet after drying.

The 2,650 cubic feet of dry tree volume would yield about 375 cubic feet of C grade and better veneer. This is not enough veneer to fully utilize the residues. Table 3 shows the problem: only 23 percent of the total tree volume is converted to full-length veneer, while 41 percent of the total tree volume is top-log residue. Southern pine stands yield 44 percent full-length veneer and have only 15 percent top-log residue (McAlister and Taras 1978). Therefore, it is likely that hardwoods can best be used in combination with softwoods—a concept unique to the COM-PLY system. Table 4 gives the average veneer yields per 100 stems for central Georgia when southern pine is included (Cathey 1972). The yields are much different because southern pine makes up almost 78 percent of the number of trees. The use of southern pine and hardwoods in proportion to their distribution yields 562 cubic feet of dry veneer for a total green tree volume of 2,558 cubic feet.

Table 1.—Average dry cubic feet of veneer by grade and diameter class in yellow-poplar, sweetgum, and white oak (central Georgia Piedmont)

Tree d.b.h. (inches)	Dry veneer volume[1]				Green block volume	Green tree volume[2]	Veneer-recovery factor[3]
	AB	C	D	Fish-tail			
	Cubic feet						*Percent*
				YELLOW-POPLAR			
12	0.2	1.5	0.7	0.4	11.7	24.7	20.5
14	0	6.4	2.6	.6	21.8	33.0	41.3
16	.2	10.1	3.9	1.3	34.0	45.4	41.8
18	.5	15.3	7.7	1.4	52.6	61.5	44.7
20	1.9	14.5	9.1	1.4	56.5	73.4	45.1
				SWEETGUM			
12	.2	2.2	.3	.3	7.0	19.3	38.6
14	.9	8.4	1.9	.9	24.2	34.4	46.3
16	.2	5.9	4.5	1.4	31.9	42.8	33.2
18	1.1	9.8	4.1	1.3	35.7	53.8	42.0
20	1.3	10.7	11.1	1.6	48.5	66.9	47.6
				WHITE OAK			
12	0	.72	.51	.37	8.74	17.9	14.1
14	0	2.39	.63	15.68	28.6	28.6	29.6
16	0	3.15	5.33	1.19	27.61	41.9	30.7
18	0	3.43	8.80	1.31	34.96	52.4	35.0
20	0	5.89	9.04	.84	40.54	68.9	36.8

[1]Full-length veneer: 102 inches long; fishtail: 54 inches long; all veneer: 0.160 inch thick and dry.
[2]Volume to a 4-inch (d.i.b.) top.
[3]Ratio of dry, full-length veneer (grades A, B, C, and D) to green block volume (Smalian).

Table 2.—Average veneer yield per 100 stems from typical natural hardwood stands in central Georgia, by species and tree diameter class

Tree diameter class (inches)	Species	No. of stems	Dry veneer volume[1]				Green block volume	Green tree volume[2]
			AB	C	D	Fish-tail		
			Cubic feet					
12	Oak	23.1	0	16.6	11.8	8.6	201.9	427.8
	Sweetgum	19.5	3.9	42.9	5.8	5.8	136.5	376.4
	Yellow-poplar	6.9	1.4	10.4	4.8	2.8	80.7	170.4
14	Oak	12.9	0	29.0	30.8	8.1	202.3	170.4
	Sweetgum	10.3	9.3	86.5	19.6	9.3	249.3	354.3
	Yellow-poplar	3.2	0	20.5	8.3	1.9	69.8	105.6
16	Oak	7.0	0	22.0	37.3	8.3	193.3	293.3
	Sweetgum	4.1	.8	24.2	18.4	5.7	130.8	175.5
	Yellow-poplar	2.5	.5	24.2	9.8	3.2	85.0	113.5
18	Oak	4.2	0	14.4	37.0	5.5	146.8	220.1
	Sweetgum	1.6	1.8	15.7	6.6	2.1	57.1	86.1
	Yellow-poplar	1.1	.6	16.8	8.5	1.5	57.9	67.6
20	Oak	2.2	0	13.0	19.9	1.8	89.2	151.6
	Sweetgum	.9	1.2	9.6	10.0	1.4	43.6	60.2
	Yellow-poplar	.5	1.0	7.2	4.6	.7	28.2	36.7
	Total	100.0	20.5	354.0	233.2	66.7	1,772.4	3,008.0
	Total oak	49.4	0	95.0	136.8	32.3	833.5	1,461.7
	Total sweetgum	36.4	17.0	178.9	60.4	24.3	617.3	1,052.5
	Total yellow-poplar	14.2	3.5	80.1	36.0	10.1	321.6	493.8

[1]Full-length veneer: 102 inches long; fishtail: 54 inches long; all veneer: 0.160 inch thick.
[2]Volume to a 4-inch (d.i.b.) top.

Table 3.—Average dry volume of veneer and residue from 100 trees of a typical hardwood stand in central Georgia

Item	Oak	Sweetgum	Yellow-poplar	Total	Proportion of stand volume
	Cubic feet				*Percent*
A and B veneer	0	17.0	3.5	20.5	0.8
C veneer	95.0	178.9	80.1	354.0	9.6
D veneer	136.8	60.4	36.0	233.2	8.8
Total full-length veneer[1]	231.8	256.3	119.6	607.7	23.0
Fishtail[2]	32.3	24.3	10.1	66.7	2.5
Total veneer	264.1	280.6	129.7	674.4	25.5
Peeling residue	469.4	262.6	153.3	885.3	33.4
Total block volume	733.5	543.2	283.0	1,559.7	58.9
Top log residue	552.8	383.0	151.5	1,087.3	41.1
Total tree volume[3]	1,286.3	926.2	434.5	2,647.0	100.0

[1]Full-length veneer: 102 inches long.
[2]Fishtail: 54 inches long.
[3]Volume to a 4-inch (d.i.b.) top.

Table 4.—Average veneer yield per 100 stems of mixed pine and hardwood for typical timber stands in central Georgia, by species and tree diameter class

Tree diameter class (inches)	Species	No. of stems	Dry veneer volume[1]				Green block volume	Green tree volume[2]
			AB	C	D	Fish-tail		
			Cubic feet					
10	Pine	35.3	21.2	63.5	14.1	10.6	345.9	533.0
12	Pine	21.8	34.9	100.3	28.3	10.9	416.4	475.2
	Oak	5.2	0	3.7	2.7	1.9	45.4	93.1
	Sweetgum	4.4	.9	9.7	1.3	1.3	30.8	84.9
	Yellow-poplar	1.6	.3	2.4	1.1	.6	18.7	39.5
14	Pine	12.2	30.5	96.4	58.6	14.6	395.3	422.1
	Oak	2.9	0	6.5	6.9	1.8	45.5	82.9
	Sweetgum	2.3	2.1	19.3	4.4	2.1	55.7	79.1
	Yellow-poplar	.7	0	4.5	1.8	.4	15.3	23.1
16	Pine	5.3	23.3	53.5	47.7	8.5	243.8	254.9
	Oak	1.6	0	5.0	8.5	1.9	44.2	67.0
	Sweetgum	.9	.2	5.3	4.0	1.3	28.7	38.5
	Yellow-poplar	.6	.1	6.1	2.3	0.8	20.4	27.2
18	Pine	2.2	17.8	22.0	29.0	4.4	125.8	139.5
	Oak	.9	0	3.1	7.9	1.2	31.5	47.2
	Sweetgum	.3	.3	2.9	1.2	.4	10.7	16.1
	Yellow-poplar	.2	.1	3.1	1.5	.3	10.5	12.3
20	Pine	.8	8.0	8.6	14.6	1.8	55.0	67.4
	Oak	.5	0	2.9	4.5	.4	20.3	34.4
	Sweetgum	.2	.3	2.1	2.2	.3	9.7	13.4
	Yellow-poplar	.1	.2	1.4	.9	.1	5.6	7.3
	Total	100.0	140.2	422.3	243.5	65.6	1,975.2	2,558.1
	Total pine	77.6	135.7	344.3	192.3	50.8	1,582.2	1,892.1
	Total oak	11.1	0	21.2	30.5	7.2	186.9	324.6
	Total sweetgum	8.1	3.8	39.3	13.1	5.4	135.6	232.0
	Total yellow-poplar	3.2	.7	17.5	7.6	2.2	70.5	109.4

[1]Full-length veneer: 102 inches long; fishtail: 54 inches long; all veneer: 0.160 inch thick.
[2]Volume to a 4-inch (d.i.b.) top.

Table 5 shows the breakdown by species. If it is assumed that the 562 cubic feet of C and better veneer would lose about 10 percent in manufacturing losses, 506 cubic feet would be left, which means that 87 percent of the total volume would be utilized in composite lumber. The harvesting of the hardwood trees at the same time as the pine and the removal of all material down to a 4-inch (d.i.b.) top would leave sites in better condition for the planting of trees. The comparatively small volume of oak residues (about 16 percent of the total) might be incorporated in the particleboard core without significant problems.

A 1/2-inch-thick COM-PLY panel with 0.1-inch-thick veneer faces requires about 40 percent veneer and 60 percent particleboard. Producers of COM-PLY panels would use veneer of all grades. The volume of full-length veneer available from peeling a typical mix of 100 trees would be 806 cubic feet. Woodfin (1973) has estimated softwood plywood manufacturing losses of about 16 percent in a panel operation. The net volume of veneer that is utilized would be 677 cubic feet, or 30 percent of the total dry volume of the timber mix. Consequently, a producer of COM-PLY panels could use about 75 percent of the total stand volume and 97 percent of the total veneer-block volume. Southern pine plywood plants achieve yields of 45 percent plywood based on veneer-block volume of southern pine alone. Therefore, a plant producing COM-PLY panels would require less than one-half the timber volume to produce an equivalent volume of pine plywood.

Hardwood veneer blocks from the lower part of the stem produce the greatest yield of C and better grade veneer. As was the case with southern pine, the first three veneer blocks (26 to 27 feet) in the stem yield most of the C grade and better veneer.

Researchers may be interested in grade yields for hardwood species based on block diameter instead of tree diameter class. These data are presented in the Appendix, tables 7 and 8.

Table 5.—Average dry volume of veneer and residue from 100 stems of mixed pine and hardwood for a typical timber stand in central Georgia

Item	Southern pine	Oak	Sweet-gum	Yellow-poplar	Total	Proportion of stand (all species)	Total hardwood	Hardwood proportion of stand volume
	.....		*Cubic feet*	.....		*Percent*	*Cubic feet*	*Percent*
A and B veneer	135.7	0	3.8	0.7	140.2	6.2	4.5	0.2
C veneer	344.3	21.2	39.3	17.5	422.3	18.8	78.0	3.5
D veneer	192.3	30.5	13.1	7.6	243.5	10.8	51.2	2.3
Total full-length veneer[1]	672.3	51.7	56.2	25.8	806.0	35.8	133.7	6.0
Fishtail[2]	50.8	7.2	5.4	2.2	65.6	2.9	14.8	.6
Total veneer	723.1	58.9	61.6	28.0	871.6	38.7	148.5	6.6
Peeling residue	669.2	115.6	57.7	34.0	866.6	38.5	197.3	8.8
Total block volume	1,392.3	174.5	119.3	62.0	1,738.2	77.2	345.8	15.4
Top log residue	272.7	121.1	84.9	34.3	512.9	22.8	240.3	10.7
Total tree volume[3]	1,665.0	295.6	204.2	96.3	2,251.1	100.0	586.1	26.1

[1]Full-length veneer: 102 inches long.
[2]Fishtail: 54 inches long.
[3]Volume to a 4-inch (d.i.b.) top.

CONCLUSIONS

The following conclusions can be drawn from the data:

1. In a typical distribution of oak, sweetgum, and yellow-poplar from central Georgia, nearly 75 percent of the total tree volume would be either tops too small to peel into veneer or peeling residue. This means that complete conversion of hardwood timber stands to COM-PLY products is not possible from hardwoods alone.

2. From the proportions of species found in a typical timber stand in central Georgia, southern pine and hardwoods can yield 87 percent of the total tree volume in COM-PLY lumber products. This percentage compares with a 25-percent yield for sawed lumber from southern pine and a 31-percent yield if both pine and hardwoods are sawed into lumber.

3. The production of COM-PLY panels from mixed pine and hardwoods in the proportions found in a typical timber stand in central Georgia would yield about 75 percent of the total stand volume. This percentage compares with a 28-percent yield of southern pine plywood and a 35-percent yield if both pine and hardwoods are made into plywood.

4. Almost all of the oak veneer and residue can be used in COM-PLY products if it is combined with mixed southern pine and hardwoods that are found in the typical stands of central Georgia.

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APPENDIX

The Appendix tables provide detailed information on veneer yields by tree diameter from the mountain areas and for veneer yields based on block diameter from both areas.

Table 6.—Average dry cubic feet of veneer by grade and d.b.h. class in yellow-poplar and white oak (southwestern North Carolina mountains)

Tree d.b.h. (inches)	Dry veneer volume[1]				Green block volume	Green tree volume[2]	Veneer recovery factor[3]
	AB	C	D	Fish-tail			
	Cubic feet						*Percent*
				YELLOW-POPLAR			
12	0	1.18	0.46	0.30	11.50	22.88	14.3
14	0	10.44	2.35	.82	31.79	44.02	40.2
16	0	15.54	10.45	1.26	51.76	57.91	50.2
18	0	16.36	12.81	2.50	64.78	77.36	45.0
20	0	18.34	18.78	1.74	76.86	96.81	48.3
22	0	20.28	31.65	2.35	98.20	110.69	52.9
				WHITE OAK			
12	0	1.82	1.69	.80	16.87	23.51	21.0
14	0	2.31	5.33	.80	28.47	36.19	26.8
16	0	3.39	8.45	.77	38.57	45.78	30.7
18	0	2.40	12.47	.62	40.83	66.58	36.4
20	0	4.90	12.24	1.72	44.30	69.27	38.7
22	0	6.97	22.48	1.76	63.05	91.43	46.7

[1]Full-length veneer: 102 inches long; fishtail: 54 inches long; all veneer: 0.160 inch thick.
[2]Volume to a 4-inch (d.i.b.) top.
[3]Ratio of dry, full-length veneer to green block volume.

Table 7.—Average veneer yield by grade and block diameter for yellow-poplar, sweetgum, and white oak (central Georgia piedmont)

Block diameter (inches)	Dry veneer volume[1]				Green block volume	Residue[2]	Veneer recovery factor[3]
	A+B	C	D	Fish-tail			
	Cubic feet						*Percent*
				YELLOW-POPLAR			
9	0	0.41	0.38	0.14	4.44	3.65	18.1
10	.05	.91	.55	.18	5.13	3.63	29.4
11	.04	1.14	.94	.20	6.36	4.24	32.8
12	0	2.34	1.24	.34	.7.40	3.82	48.2
13	.08	1.93	1.75	.24	8.93	5.17	41.9
14	.19	3.53	.95	.24	10.25	5.58	46.1
15	.48	4.54	1.18	.17	11.87	5.67	52.3
16	.24	4.86	1.65	.37	13.59	6.84	49.8
17	.95	6.97	1.41	.32	16.27	6.93	57.3
				SWEETGUM			
9	0	.89	.27	.20	4.63	3.47	23.8
10	.13	1.38	.65	.24	5.15	2.99	42.0
11	.17	1.66	.66	.18	6.11	3.62	39.7
12	.17	1.93	1.21	.29	7.67	4.36	42.5
13	.07	2.06	1.27	.37	9.03	5.64	37.6
14	.76	2.89	1.27	.25	10.42	5.50	48.1
15	.38	3.24	2.78	.42	11.70	5.30	54.8
16	0	1.66	4.65	.62	15.78	9.48	40.3
17	0	7.35	.22	.98	16.45	8.88	46.0
				WHITE OAK			
9	0	0	.18	.30	4.06	3.87	4.4
10	0	.49	.69	.15	5.27	4.09	21.9
11	0	.78	1.11	.30	6.81	4.91	27.0
12	0	.17	1.50	.50	7.38	5.71	22.3
13	0	1.55	2.16	.30	9.30	5.58	39.7
14	0	1.04	2.42	.39	10.05	6.59	34.4
15	0	1.56	3.00	.33	12.67	8.10	36.0
16	0	0	1.38	.07	13.48	12.10	10.2
17	0	.52	5.55	.29	15.04	8.97	40.3
18	0	4.79	3.08	.52	17.32	9.46	44.6

[1]Full-length veneer: 102 inches long; fishtail: 54 inches long; all veneer: 0.160 inch thick.
[2]Green block volume minus full-length veneer volume.
[3]Full-length veneer volume/green block volume × 100.

Table 8.—Average veneer yield by grade and block diameter from yellow-poplar and white oak from mountain area (southwestern North Carolina mountains)

Block diameter (inches)	Dry veneer volume[1]				Green block volume	Residue[2]	Veneer-recovery factor[3]
	AB	C	D	Fish-tail			
	Cubic feet						Percent
				YELLOW-POPLAR			
9	0	0.16	0.38	0.10	4.31	3.77	12.0
10	0	.52	1.18	.17	5.16	3.45	32.5
11	0	1.72	.74	.12	6.27	3.81	39.8
12	0	1.49	1.40	.28	7.39	4.50	39.5
13	0	2.44	1.96	.20	8.67	4.27	51.0
14	0	2.33	2.77	.24	9.86	4.76	51.6
15	0	2.38	3.66	.32	11.48	5.44	52.4
16	0	3.42	3.78	.42	12.89	5.69	56.0
17	0	4.70	3.11	.23	14.05	6.23	55.7
18	0	4.33	3.50	.52	16.43	8.61	47.8
19	0	5.91	4.08	.48	17.90	7.92	55.6
20	0	8.74	3.27	.20	20.81	8.80	57.7
				WHITE OAK			
9	0.57	.57	.55	.09	4.15	2.45	40.7
10	0	.25	.47	.16	5.13	4.41	14.1
11	0	.57	1.58	.24	6.31	4.16	34.1
12	0	1.06	2.04	.22	7.59	4.49	40.6
13	0	.42	1.72	.27	8.77	6.63	24.8
14	0	1.22	3.49	.22	10.62	5.91	43.7
15	0	.33	3.39	.22	11.23	7.51	33.2
16	0	1.91	4.62	.20	12.61	6.08	51.7
17	0	1.63	4.31	.56	15.01	9.07	30.0
18	0	1.44	8.14	.62	17.76	8.18	55.9
19	0	6.62	3.76	.33	20.38	10.0	50.9

[1]Full-length veneer: 102 inches long; fishtail: 54 inches long; all veneer: 0.160 inch thick.
[2]Green block volume minus full-length veneer volume.
[3]Full-length veneer volume/green block volume × 100.

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McAlister, Robert H.

1980. Evaluation of veneer yield and grades from yellow-poplar, white oak, and sweetgum from the Southeast. USDA For. Serv., Res. Pap. SE-220, COM-PLY Rep. 19, 12 p. Southeast. For. Exp. Stn., Asheville, N.C., and U.S. Dep. Housing and Urban Dev., Washington, D.C.

Dry volume yields and standard grades of veneer are given for yellow-poplar, sweetgum, and white oak by tree diameter and location within the stem. Results show that the typical stands of mixed southern pine and hardwood timber yield enough veneer to utilize almost 90 percent of the stand volume in the production of COM-PLY lumber and panels.

KEYWORDS. COM-PLY, lumber, panels, *Liriodendron tulipifera* L., *Liquidambar styraciflua* L., *Quercus* sp.

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Multiresource Inventories:

Procedures for Assessing the Damage Caused by Insects and Diseases

by William R. Jacobi, Robert L. Anderson,
and Noel D. Cost

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Multiresource Inventories: Procedures for Assessing the Damage Caused by Insects and Diseases

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ABSTRACT.—Valuable data on damage to trees by insects and diseases are being gathered in the forest surveys of Southeastern States. The types of damage tallied in these inventories are described, along with examples of the ways in which the data can be tabulated and interpreted.

Keywords: Forest surveys, disease incidence, insect incidence.

State and regional data are urgently needed to assess the distribution, intensity, and losses caused by a variety of insects and diseases. Pest evaluation projects, control projects, pilot tests, and research projects are but a few of the activities requiring these data. Incidence and loss assessment surveys by Forest Pest Management personnel are expensive, time consuming, and mileage intensive, and in most cases one survey cannot be compared to another.

Since Renewable Resources Evaluation (RRE) units provide a continuous inventory of the Nation's forest resources, it seems logical to incorporate the inventory of damaging agents in their State surveys. This approach is cost effective, and the data collected have several attractive attributes: (1) large numbers of plots located systematically across States and major portions of States, (2) statistically valid samples, (3) validity for regional comparisons, and (4) accurate measures of change because plots are revisited. Forest Pest Management and RRE have cooperatively developed inventory procedures that gather the necessary information in a practical manner. The procedures and the sorts of information they generate are described in this paper.

BACKGROUND

The Southeast encompasses the five States of Virginia, North Carolina, South Carolina, Georgia, and Florida. The topography varies from the Appalachian Mountains in the west through the rolling Piedmont, and to the extensive Coastal Plain. Thus, there is a considerable range of forest types along with associated diseases, insect pests, and other damages.

The Forest Service began to inventory the forest lands of the Southeast about 1933 in Florida and Georgia. Mortality and damage to living trees by diseases, insects, and fire have been estimated in each survey since then. The damage types used in

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North Carolina are similar to those used throughout the Southeast. In the first survey of North Carolina in 1937-38, damage by fire and heartrot were emphasized. Damage types tallied were butt rot, top rot, crook, sweep, and other agents. In the second survey of the Southeast, which began in 1946, losses to bark beetles, other insects, littleleaf disease, fusiform rust, and other diseases were tallied. This survey, along with others throughout the United States, was the basis for the classic paper on forest protection by Hepting and Jemison (1958) in the so-called Timber Resources Review (TRR). This analysis led to the general recognition that destruction of timber by fungi, insects, animals, and other agents was about 45 percent of the timber harvest. The third survey of the Southeast began in 1957 and ended in 1966. Many diseases and insects, acting alone or in combination, were recognized: littleleaf, fusiform rust, oak wilt, other diseases, littleleaf and fusiform, littleleaf and other diseases, fusiform and other diseases, oak wilt and other diseases, southern pine beetle, black turpentine beetle.

Following the third survey, very general damage types, including only bark beetles and fusiform rust, were adopted. This approach was used primarily because (1) survey crews were not being properly trained to collect more detailed information, and (2) pathologists and entomologists were not making use of the pest damage information.

In 1972, 14 years after the TRR was published and 20 years after the data were collected, the TRR was still the primary source of estimates on which to base research, management, and extension decisions on forest insects and diseases in the South. Thus, one could only update losses by using the 1952 data on volume loss and current prices. To update loss estimates in North Carolina, a new and more complete set of damage types was developed in 1973 in negotiations among personnel of North Carolina State University, the North Carolina Forest Service, and Forest Insect and Disease Management and RRE in the U.S. Forest Service. Types tallied were: heartrot, branch stubs, top breakage, logging and related, fire, other basal defects, animal, weather, suppression and stagnation, form (damaging), insects, fusiform rust, annosus root rot, littleleaf disease, white pine, blister rust, hardwood cankers, other diseases, turpentining, and no damage.

The following criteria were used to decide what types of damage could be assessed: (1) Is the intensity of sampling adequate to obtain reliable data? (2) Can adequate training be provided for field crews? (3) Will use of the information be sufficient to justify the costs required to obtain it? (4) Can the causal agent of damage be identified reliably in all seasons of the year?

Only general mortality types were recognized because the specific cause of mortality could not be determined for many trees that had died in the 10 years since the last survey. An audiovisual and field-training program was developed for the field crews by the cooperating agencies.

The fourth survey of North Carolina was completed in 1975 and the damage types, with modification to suit regional or State requirements, have been used in subsequent State surveys. In this paper, the types of damage are described along with examples of compilations and interpretations that can be made.

CURRENT PROCEDURES

The procedures used in North Carolina have been modified and applied in Virginia, South Carolina, Florida, Tennessee, and Puerto Rico. These techniques are being applied in surveys currently underway in Georgia and Alabama.

In any State, the first step is to select the damage types to be surveyed. Selection is done in cooperation with all interested State and Federal personnel. The symptoms must be durable, present year round, and relatively common. The damage types listed and described below are normally selected if present in the State:

Hardwood borers.—All hardwoods. The initial symptom is a dark sap spot on the bark surface (often mixed with frass). Eventually, coarse boring particles appear in bark cracks and crevices beneath the point of attack. Old damage appears as knobby overgrowths or scars on the bark surface.

Bark beetles.—All pines. Cream to yellow and pinkish globs of resin resembling popped corn on bark surface. If the infestation is well established and some trees still retain their foliage, tunnels or egg galleries are evident on the inner-bark surface and on the surface of the sapwood. Streaks caused by blue stain fungi are often also evident on sapwood. Foliage gradually yellows, then reddens.

Terminal, shoot-system borers.—All species. Fresh attacks show boring dust and frass at the entrance holes, located most often at the base of leaf petioles and buds. White to pinkish globs of resin may appear at point of attack. Older attacks are seen as terminal and/or branch dieback due to larval tunnels within the terminal and/or branch. Shoots will show yellow, then red, and finally brown needle color.

Other insects.—All tree species. All damage caused by insects not identified in separate cate-

gories. Includes hardwood defoliators (e.g., variable oak leaf caterpillars and forest tent caterpillars) and pine defoliators (e.g., redheaded pine sawfly and pine weevils).

Fusiform and comandra rust.—Slash, loblolly, pitch, pond, and shortleaf pines. These rusts typically cause the formation of spindle-shaped galls on the stem or branches; many older galls appear as cankers with sunken rotten centers encircled by a callus ridge. Witches brooming is common at galls. The fungus fruit in the spring, producing bright-orange spores. For reporting purposes, consider all stem cankers but only those branch cankers occurring within 12 inches of the bole.

Root rots.—All species. Look for groups of dead or windthrown trees—trees with tufted, thin crown which may be yellowing. Conks (fruiting bodies) of various fungi may be present on or near base of diseased trees. Disease is more frequent in trees of reduced vigor, thinned stands, and in trees with butt or root injury. Bark beetles often follow.

Littleleaf disease.—Shortleaf and loblolly pines; shortleaf is more susceptible. Affected trees occur in groups. Typically seen are yellow needles, reduced shoot growth, and large crops of undersized cones. This disease usually occurs where heavy soils having poor internal drainage dominate the site.

White pine blister rust.—Eastern white pine. This disease appears as spindle-shaped swellings on bole or branch bordered by a yellowish discoloration of the bark. Branches and tops flag as the fungus girdles the living tissue. This disease usually occurs at elevations above 3,000 feet.

Hardwood cankers.—All hardwoods. Affected trees have dead sunken areas on the stem, frequently with annual callus ridges around the dead areas.

Branch stubs.—All species. Branch holes or stubs greater than 4 inches in diameter on the stem (trees 5.0 inches d.b.h. and larger). Branch holes or stubs greater than 1 inch in diameter on stem (trees 1.0 to 4.9 inches d.b.h.).

Basal defects.—All species. Butt swelling, curls, V-shaped stump sprouts, frost seams, and low stubs below d.b.h. are symptoms of basal defect. Conks of decay fungi are often associated with defect.

Pitch canker.—Virginia, slash, shortleaf, longleaf, loblolly, eastern white, Scotch, Table Mountain, and pitch pines (primarily slash, loblolly, and shortleaf). Flagging at ends of branches, pitch flow from affected area, slight swelling on affected stems and twigs; commonly there are crooks in main stems and wilting of current candles. In early stages, there is a slight depression of the bark.

Other diseases.—All species. All damage caused by disease not identified in separate categories, e.g., red heart of pine, brown spot, and leaf diseases. Trees showing disease-caused degrade not identified elsewhere should be coded here.

Fire.—All species. Fire scars are usually at base of stem; widespread occurrence in stand. Usually on uphill side on slopes. Signs of charring are generally present on the stem.

Animal.—All tree species. Branches clipped off or broken, the bark removed, holes in stem, tears and toothmarks in the wood are all common symptoms of animal activity.

Beaver.—All species. Beavers leave toothmarks and remove bark from the bole of the tree. Trees are often flooded by water impoundment.

Sapsucker.—All species. Look for horizontal rows of small holes that may encircle the tree's bole. The bark below the hole is usually streaked or stained by oozing sap.

Weather.—All species. Windthrow, ice, frost crack (above d.b.h. for report), broken top, broken branches, marginal leaf burn, and winter burn are the common symptoms.

Flooding.—All species. Yellowing and/or curling downward of leaves, premature leaf-fall, branch and top dieback, tree mortality, and high water and silt marks on tree boles are the most common effects of flooding.

Lightning.—All species. Lightning causes bark stripping or cracks with damage running from strike point to ground, spirally or straight. Tops fading from root damage or top breakage. Bark beetles often invading struck trees.

Suppression and stagnation.—All species. Suppressed and stagnated trees are characterized by poor form, and small crown-suppressed trees are overtopped and receive indirect sunlight. Stagnated trees have thin foliage and receive some direct sunlight. Stagnation is usually associated with poor growing sites or overstocked stands.

People.—All species. Initials in bark, nails in tree, lantern burn, bark stripped, calloused roots, wire around stem, and ax marks are symptoms of damage caused by people.

Logging and related.—All species. Logging scars on stem have callus ridges within 1 to 2 years after wounding. They are scattered in stand and show no charring. Limb breakage and/or stem scar near crown caused by felling of other trees. Look for skid trails, stumps, etc.

Turpentining.—Longleaf, slash, and loblolly pines. Damage is seen as exposed wood with V-shaped wounds and heavy pitch flow.

Form (damaging).—All species. All trees with form damage that cannot be classified in one of the other categories.

Dieback.—All hardwoods. Tips of the branches dead. Just a few branches are affected at first, with whole branches dying in advanced stages. Tree mortality may result. Dieback is frequently associated with stress caused by unfavorable environment.

A field-training manual (General Report SA-GR-14) with detailed descriptions and color photographs is available from:

Southeastern Area, State and Private Forestry
P.O. Box 5895
Asheville, North Carolina 28803

Forest Pest Management then provides classroom training to the RRE crews on how to identify the damage types. During this training session, a manual is given to each crew for training and reference. The manual contains pictures, descriptions, and codes of each damage type for the State. Followup field training is then provided by the same team. All crews are given a sample kit so they can send samples to Forest Pest Management if they find a symptom they cannot identify.

Since only one damage type can be selected per tree, the following selection logic is used: (1) If a damage type will cause death of a tree, code it first. (2) In the absence of 1, record the damage type that will cause the most degrade. (3) In the absence of 1 or 2, record the damage type that will cause the most growth loss. (4) In the absence of 1, 2, or 3, record the most common damage type.

Based on this training, field crews record the occurrence of damage types for each tree over 1 inch in diameter. Standard RRE procedures are used throughout the survey. Standard tables are generated by RRE at the completion of each survey. Information in such tables includes:

- Area of commercial forest land, by stand-size class and forest type.
- Number of susceptible trees damaged, by species and tree size.
- Damage incidence and associated culls in a softwood species.
- Damage incidence and associated culls in a hardwood species.
- Timber removals and wood loss to pole-timber and sawtimber.
- Annual economic impact of damage to the timber resource.
- Past stand treatment or disturbance as related to treatment needed by number of samples.

Examples are provided in tables 1 to 7.

A text based on the tables is then prepared for each State, appropriate reviews are made, and a State Resource Bulletin is prepared.

Table 1.—Area of commercial forest land, by stand-size class and forest type

Forest classification	Acres
Stand-size class:	
Sawtimber	5,454,246
Poletimber	3,552,830
Saplings–Seedlings	3,223,313
Nonstocked areas	272,517
All stand sizes	12,502,906
Forest type:	
White pine–Hemlock	13,374
Longleaf pine	471,112
Slash pine	512,137
Loblolly pine	3,403,718
Shortleaf pine	655,877
Virginia pine	178,021
Eastern redcedar	22,764
Pond pine	301,549
Spruce pine	7,735
Pitch pine	4,633
Oak–Pine	1,718,544
Oak–Hickory	2,694,392
Chestnut oak	4,405
Southern scrub oak	246,457
Oak–Gum–Cypress	1,990,754
Elm–Ash–Cottonwood	277,434
All types	12,502,906

Table 2.—Number of susceptible trees damaged, by species and tree size

Host	Total population (thousands)	Trees damaged		
		Saplings	Poletimber	Sawtimber
		Percent		
SOFTWOODS				
Loblolly pine	1,419,134	34	25	20
Longleaf pine	128,954	12	17	14
Pitch pine	1,348	0	0	14
Pond pine	103,058	42	32	27
Shortleaf pine	535,107	25	9	9
Slash pine	193,131	39	44	33
Spruce pine	4,469	57	16	22
Virginia pine	120,536	29	12	15
Baldcypress	27,420	27	11	17
Atlantic white-cedar	429	0	0	29
Hemlock	605	0	0	8
Pondcypress	41,036	20	14	16
Redcedar	235,583	23	9	9
White pine	6,344	24	0	6
HARDWOODS				
Basswood	285	0	12	52
Black cherry	106,928	92	33	44
Cottonwood	8,694	66	24	29
Elm	189,199	69	15	36
Sweetgum	1,226,273	50	19	22
Sycamore	4,661	59	21	21
Yellow-poplar	122,951	33	16	17
Ash	287,671	78	24	29
Beech	12,053	27	8	53
Black locust	1,628	0	37	48
Black walnut	2,706	72	40	34
Hickory	259,151	54	17	23
Chestnut oak	16,136	58	15	33
Select red oaks	55,563	55	17	20
Select white oaks	209,061	45	13	28

Table 3.—Damage incidence and associated cull in loblolly pine
(1,419 million susceptible trees)

Damage	Incidence of damage			Associated cull		Accumulated volume loss		Associated volume loss from sawtimber to poletimber
	Saplings	Poletimber	Sawtimber	Poletimber	Sawtimber	Poletimber	Sawtimber	
	Percent					*M ft³*	*M bf*	*M bf*
Insect	0	0.10	0.26	0	0.57	0	284	0
Other disease	.05	.37	.58	1.25	.84	61	911	0
Fusiform rust	16.07	17.14	12.07	.08	.28	180	628	1.418
Littleleaf disease	0	.05	.01	0	0	0	0	0
Branch stubs	0	.01	0	5.00	0	7	0	0
Top breakage	.16	.18	.21	9.44	9.17	223	3,584	20
Other basal defects	0	.03	.12	5.00	13.00	20	2,896	0
Fire	.36	.42	.54	.31	1.57	17	1,580	20
Animal	0	0	.12	0	0	0	0	0
Weather	.11	.66	.98	.55	.67	48	1,215	0
Suppression & stagnation	1.99	.50	.11	0	0	0	0	0

Table 4.—Damage incidence and associated cull in black cherry
(107 million susceptible trees)

Damage	Incidence of damage			Associated cull		Accumulated volume loss		Associated volume loss from sawtimber to poletimber
	Saplings	Poletimber	Sawtimber	Poletimber	Sawtimber	Poletimber	Sawtimber	
	Percent					*M ft³*	*M bf*	*M bf*
Other disease	2.78	4.52	5.62	0	0	0	0	0
Hardwood cankers	1.94	5.32	0	0	0	0	0	0
Branch stubs	.25	.75	14.46	5.00	7.50	9	506	0
Top breakage	1.55	6.88	0	26.25	0	421	0	0
Other basal defects	.76	1.02	13.65	47.50	12.50	113	790	0
Fire	.29	.93	0	2.50	0	5	0	0
Weather	0	.57	.80	15.00	0	20	0	0
Suppression & stagnation	1.01	1.02	0	0	0	0	0	0

Table 5.—Timber removals and wood loss to poletimber and sawtimber

Species	Annual timber removals		Volume loss due to—				Total quality loss from sawtimber to nonsawtimber
			Mortality		Total accumulated cull		
	Poletimber	Sawtimber	Poletimber	Sawtimber	Poletimber	Sawtimber	
	M ft^3	*M bf*	*M ft*^{3}	*M bf*	*M ft*^{3}	*M bf*	*M bf*
			SOFTWOODS				
Yellow pines[a]	58,105	1,330,964	43,298	192,830	552	412	97
Eastern white pine	0	2,120	0	0	0	34	0
Cypress[b]	0	23,443	644	761	189	2,109	20
Other eastern softwoods[c]	509	3,967	488	4,724	517	469	8
Total	58,614	1,360,494	44,430	198,315	1,258	3,024	125
			HARDWOODS				
Selected white & red oaks	3,244	73,788	684	4,080	340	1,607	44
Other white & red oaks[c]	9,663	137,887	5,321	36,531	9,532	14,070	423
Hickory	1,427	20,602	170	2,842	1,083	1,572	26
Hard maple	0	0	0	0	30	193	8
Sweetgum	7,000	89,001	2,182	20,287	4,484	5,632	78
Ash, walnut, black cherry	618	11,347	1,701	5,193	2,023	1,440	35
Yellow-poplar	354	38,091	838	4,231	892	1,986	29
Tupelo & blackgum	2,898	66,868	601	8,665	3,576	20,074	637
Bay & magnolia	0	0	131	0	14	349	8
Other eastern hardwoods[f]	3,144	44,267	4,091	32,653	10,958	13,480	477
Total	28,348	481,851	15,719	114,482	32,932	60,403	1,765
All species	86,962	1,842,345	60,021	312,797	34,190	63,427	1,890

[a]Loblolly, shortleaf, Virginia, pitch, pond, Table Mountain.
[b]Baldcypress and pondcypress.
[c]Cedar and hemlock.
[d]White, swamp chestnut, cherrybark, northern red.
[e]Chestnut, post, water, southern red, scarlet, black.
[f]Basswood, cottonwood, elm, sycamore, beech, black locust, and soft maple.

Table 6.—Annual economic impact of damage to the timber resource

Species	Annual volume of wood-fiber loss	Stumpage value per unit	Dollar loss
		Dollars	
Softwoods:			
Sawtimber (M bm)[a]	205,945	124.10/M	25,557,775
Poles (M ft^3)[b]	44,615	17.63	786,562
Hardwoods:			
Sawtimber (M bm)	229,930	64.11	14,740,812
Poles (M ft^3)	19,009	5.09	96,756
All species:			
Sawtimber (M bm)	435,875		40,298,587
Poles (M ft^3)	63,624		883,318
Total			41,181,905

[a] 1 ft^3 = 4.5 fbm.
[b] 1 cord = 75 ft^3.

Table 7.—Past stand treatment or disturbance as related to treatment needed, by number of samples

Item	Treatment needed							
	None	Salvage	Harvest	Thinning	Cleaning	Stand conversion	Artificial regeneration	Total
Wildlife	37	2	1	2	6	5	26	79
Man-caused flooding	2	1	0	0	1	0	5	9
Grazing	42	0	3	2	2	0	7	56
Construction	26	0	3	3	3	0	10	45
Salvage cut	6	1	1	1	1	2	4	16
Significant disease	84	15	0	21	6	6	8	140
Significant insect	32	4	5	3	2	0	11	57
Significant natural	20	2	1	1	2	4	5	35
Total of all samples, including temporary plots	2,445	39	257	181	269	176	763	4,130

USES OF DATA

A wide variety of data manipulations, in addition to the data presented in tables 1 to 7, can be performed depending on the information needed. The survey data in North Carolina provided the basis for the first analysis since 1952 of damage incidence (Jacobi and others 1980a, 1980b, 1980c), financial loss due to mortality, and cull (volume losses) due to the various types of damage (Phelps and McClure 1976). Excerpts of the analysis of North Carolina damage information are given here. North Carolina is broken down into four survey units based on physiography (fig. 1). Incidence data on most tree species can be analyzed from these or smaller units, depending on the intensity of sampling. From the survey data, an overall picture can be obtained of the relative importance of various damaging agents on softwoods and hardwoods (table 8). Of those damages recorded, heartrots, fusiform rust, form damage, and suppression and stagnation were the most prevalent in North Carolina. The size class and geographic distribution of diseases such as fusiform rust are also easily determined from the data (table 9). Table 10 provides examples of the types of information one can derive about major types of damage. It shows the geographic distribution, apparent cause, and volume losses due to heartrot in diffuse porous hardwoods.

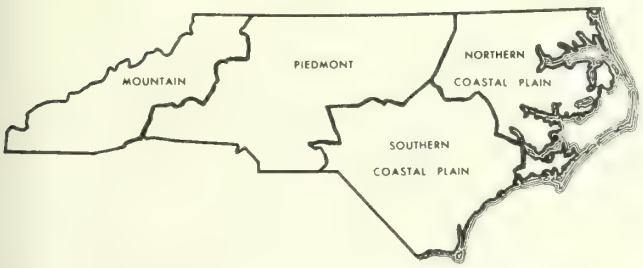

Figure 1.—Map of survey units in North Carolina.

The benefits of obtaining data through RRE Surveys are fairly obvious: (1) One can obtain good data without setting up expensive and time-consuming surveys. (2) The data are collected in the same manner throughout a region, so comparisons can be made across large areas. (3) Supporting data collected at the sample plots indicate site class, stand age, stand composition, stand size, shrubs and other lesser vegetation, past land utilization, and soil types. (4) RRE can provide computer support services to cooperators.

The RRE survey methods impose some inherent limitations on damage assessment. The need for durable symptoms and signs for year-round sampling eliminates many foliar diseases, root rots, and wilts from the survey. Specific causes of mortality are very difficult to determine because of the 8 to 9 years between surveys and the rapid decay of trees. Additionally, the intensity of sampling does not allow the assessment of problems restricted to certain areas or with low incidences. The RRE estimates of damage incidence and volume loss are not the answer to all needs for information on insects and diseases, but they provide excellent information on certain problems and a backbone for a comprehensive and continuing assessment of our forests.

Table 8.—Incidence of various types of damage to trees in North Carolina, 1973–74

Size class	Type of damage						
	Cankers	Fusiform rust	Heart-rot	Other diseases	Insects	Damaging form	Suppression or stagnation
	Percent						
Softwoods:							
Saplings[a]	--	3.1	1.0	0.6	0.1	16.6	5.1
Poletimber[b]	--	1.6	2.1	.7	.3	2.3	2.0
Sawtimber[c]	--	1.0	4.6	1.0	.5	2.6	.6
All trees	--	1.9	1.6	.6	.04	13.7	4.0
Hardwoods:							
Sapling	0.2	--	.9	.07	.01	60.4	.8
Poletimber	.6	--	7.0	.08	.12	7.8	1.0
Sawtimber	.8	--	16.0	.33	.01	6.9	.4
All trees	.3	--	2.4	.08	.02	48.9	.9

[a]Trees 2.5–12.7 cm (1–5 inches) in diameter at breast height (d.b.h.).
[b]Trees 12.7–22.8 cm (5–9 inches) in d.b.h. for softwoods. Trees 12.7–28 cm(5–11 inches)in d.b.h. for hardwoods.
[c]Trees >22.8 cm (9 inches) in d.b.h. for softwoods. Trees >28 cm (11 inches) in d.b.h. for hardwoods.

Table 9.—Size class and geographical distribution of fusiform rust on susceptible pines in North Carolina, 1973–74

Host	Size class			
	Sapling[a]	Poletimber[b]	Sawtimber[c]	Total
	Percent of trees infected			
Southern Coastal Plain:				
Slash pine	16	21	--	17
Loblolly pine	10	8	5	9
Pond pine	5	7	13	6
Northern Coastal Plain:				
Slash pine	--	16	--	--
Loblolly pine	7	4	2	6
Pond pine	1	2	2	2
Piedmont:				
Loblolly pine	4	3	1	3

[a]Trees 2.5–12.7 cm (1–5 inches) in diameter at breast height (d.b.h.).
[b]Trees 12.7–22.8 cm (5–9 inches) in d.b.h.
[c]Trees 22.8 cm (9 inches) in d.b.h.

Table 10.—Geographical distribution, apparent cause, and amount of cull due to heartrot in diffuse porous hardwood sawtimber in North Carolina, 1973–74

Apparent cause	Coastal Plain		Piedmont	Mountains	Average	Volume of cull in affected trees
	Southern	Northern				
	Percent					
Branch stubs	2.0	2.1	2.8	2.3	2.3	14
Top breaks	7.1	7.5	4.1	1.9	5.2	25
Fire scars	.4	.1	.05	.2	.2	2
Logging wounds	1.5	1.7	1.3	.1	1.2	8
Other basal defects	15.2	12.0	6.5	14.7	12.1	27

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KEYWORDS: Forest surveys, disease incidence, insect incidence.

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End Bearing and Joint Strength of COM-PLY Joists

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REPORT

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Southeastern Forest Experiment Station

Asheville, North Carolina

End Bearing and Joint Strength of COM-PLY Joists

by
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Cooperative Research by
U.S. Department of Agriculture, Forest Service
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and
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PREFACE

This report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in houses. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem and that long-range plans for better use of the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with particleboard and veneer as a way of using not only more of the tree stem, but also of using less desirable trees and a greater variety of tree species than would conventional wood products. The particleboard, which forms a large portion of COM-PLY studs and joists, is made from chipped-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Georgia. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid-wood lumber, suggest performance standards for composite lumber, and provide construction details for incorporating such lumber in houses. Still others will explore the economic feasibility of manufacturing composite lumber and panels, and will estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

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ABSTRACT.—COM-PLY joists supported by four common methods were evaluated. These are: by end bearing on wood plates, by ledgers with end notching, by end bearing on metal joist hangers, and by nails only. Results show that end bearing and joint strength of COM-PLY joists proved satisfactory for all four common methods of support.

Keywords: Composite lumber, particleboard, veneer, floor performance, joist hangers, nailed joint strength, ledgers.

A new composite lumber product called COM-PLY is being developed through cooperative research by the Forest Service, U.S. Department of Agriculture, the Department of Housing and Urban Development, and several manufacturers of forest products. This product, designed to utilize trees and wood residues more efficiently, is a structural sandwich construction consisting of approximately 73 percent particleboard and 27 percent veneer of solid wood. The veneer facings are made from high-quality wood peeled from the outer portions of healthy trees, but the particleboard core can be made from forest and mill residues and low-quality timber. This report is one in a series on development of COMPLY joists for use in floors of single-family homes, apartments, and other light-frame structures. A method for evaluating end bearing and joint strength of COM-PLY joists and the results of such an evaluation are described here.

Typically, floor joists are supported by one of four methods. The most common is a wood sill plate at each end of the joist. Sometimes the joists are notched and supported by a nominal 2 by 2 ledger attached to the side of a wood beam. A third method is the use of a metal joist hanger specifically designed to transfer heavy loads from the joist to a beam. In some special cases, such as the tail joist that occurs around a stairwell, and when the tail joist span is 6 feet or less, the ends may be supported only by nails. The purpose of this report is to determine the load-deformation characteristics of each method of COM-PLY joist support. Then it will show how safe-design loads and limits on deformation are computed from the load-deformation characteristics of the joist-support method.

MATERIALS

As test specimens, 16 COM-PLY joists 1½ by 7¼ by 96 inches were fabricated and cut to required lengths. These joists were made from rotary-cut southern pine veneer laminated to the 1½-inch edges of particleboard cores. From randomly selected sheets of various widths of ¼-inch-thick veneer 100 inches long, we ripped 128 strips 1½ inches wide. These strips were trimmed to a length of 96 inches.

The average dynamic modulus of elasticity (MOE_d) for the strips was determined to be 2.26×10^6 lb/in^2 by the stress-wave method described by Koch and Woodson (1968).

The core material used in this study was a phenolic-bonded particleboard 1½ inches thick. Particleboard had an average density of 40 lb/ft^3, an internal bond of 75 lb/in^2, an MOE (in plane of panel) of 300,000 lb/in^2, a modulus of rupture (MOR) of 3,400 lb/in^2, and contained 8 percent phenolic resin binder throughout the three layers. This core furnish material was made from southern pine planer shavings, slabs, edgings, and other mill residues. Sixteen core strips were ripsawn from 4- by 8-foot sheets to a width of 5.25 inches.

Each COM-PLY joist was fabricated by laminating four randomly selected veneer strips to each 1½-inch edge of particleboard core. Each piece of veneer was coated on its loose face with phenol-resorcinol laminating adhesive at a spread rate of 0.06 lb/ft^2 with a hand roller. The narrow edges of the core material were coated with the same glue at a spread rate of 0.10 lb/ft^2. The veneer was then placed glue side toward the core and the assembly allowed to set in closed position for a minimum of 15 minutes and a maximum of 30 minutes at 70° F. Pressure was applied with bar clamps torqued to provide about 125 lb/in^2 clamping pressure. The assembly was allowed to set overnight at room temperature for curing.

For the solid-lumber test specimens, No. 2 grade spruce 1½ by 7¼ by 96 inches was selected from stocks of local lumber dealers. Only those portions of the spruce joist that were straight and relatively free from knots and other defects were used in tests.

All COM-PLY and spruce test specimens were conditioned to a constant weight at 70° ± 3° F and a relative humidity of 60 ± 5 percent before being cut to various lengths and assembled as required.

GENERAL PROCEDURES

Testing procedures were similar to those described in ASTM D 1761-74 (ASTM 1975c) for testing metal joist hangers. This method permits evaluation of vertical load-carrying capacity and deformation characteristics of metal joist hangers and similar devices used to connect wood joists to headers of wood or other material. This method was modified as necessary to test the four types of joist supports. Torsional moment capacity was not measured in this study because we were only concerned with floor joists which are loaded vertically downward.

Ten specimens of each type of joist support were tested. All specimens requiring fastenings with nails were tested within 1 hour after assembly as recommended by ASTM methods. Joint deformation and ultimate load were determined for each group. Ultimate load is that when deformation occurs at an increasing rate per unit of time with no increase in load, when the specimen has collapsed, or when the specimen in direct end bearing has deformed a total of 0.125 inch.

The specimens were placed in a universal testing machine capable of operating at a constant rate of head speed of 0.035 inch per minute ± 50 percent and with an accuracy of ± 1 percent when calibrated in accordance with ASTM Method E-4 (ASTM 1975d). Vertical movement of the joist with respect to the header or plate was measured at a point three-fourths of an inch from the end of each joist on a dial gage with a least reading of 0.001 inch (see figs. 1, 2, 4, 5). Loads were recorded at deformation increments of 0.005 inch up to a deformation of 0.025 inch and at increments of 0.010 inch up to a deformation of 0.125 inch. Ultimate load was recorded to the nearest 10 pounds.

The test load was applied at the center of the specimen's span through a spherical bearing block to equalize the load at each end of the specimen. Load on the joint was one-half of the applied load. Test span for all four support methods was 20 inches.

After completing tests on each group of joints, the average and the standard deviation for the ultimate loads of the group were computed according to accepted statistical procedures. Also the average and the standard deviation for joint deformations of each group were calculated. Next, allowable design loads were computed by one of two procedures. In procedure I, the calculated averages and standard deviations were used to compute the adjusted values for loads and deformations according to the formulas given in the "Performance Standards for Composite Studs Used in Exterior Walls" (Blomquist and others 1978).

The formula for computing the adjusted value for load was:

$$P = \left[\bar{p} - \frac{t_{0.05} S}{\sqrt{N}} - t_{0.05} S\right] \frac{1}{F_s F_t}$$

where:

- P = adjusted value for load in pounds per joint
- $\bar{p}$ = one-half of the average ultimate test load in pounds
- $t_{0.05}$ = statistical t at 0.05 confidence level for N-1 degrees of freedom
- S = standard deviation of ultimate joint loads (one-half of ultimate test load) in pounds
- N = number of test specimens
- F_s = factor of safety; use 1.5
- F_t = adjustment for the ratio of the duration of test load to the duration of the service load. In this case, the service load is assumed to be a normal load, and the factor for the duration of this load is 1.0. If the test load is applied over an average period of 10 minutes, the factor for the duration of this load is 1.59. In this example, the test load is applied faster than the service load, so the adjustment factor is 1.59/1.0 or 1.59 (Hunt and others 1973; ASTM 1975a).

For joint deformation the adjusted value is computed by the formula:

$$D = \bar{d} + \frac{t_{0.05} S}{\sqrt{N}}$$

where:

- D = adjusted value for joint or bearing deformation of joist relative to header or bottom of sill plate, in inches.
- $\bar{d}$ = the average joint deformation on N test joints when the load is applied to the joint or bearing surface equal to the calculated value of P
- $t_{0.05}$ = statistical t at 0.05 confidence level for N-1 degrees of freedom
- S = standard deviation of joint deformation under the calculated value for P
- N = number of specimens.

These formulas from Blomquist and others (1978) were designed to determine safe loads and safe deformations for a group of joists by penalizing materials with wide variations in strength properties. Thus, when ultimate strength values vary widely, they are reduced more by the formulas for computing the adjusted loads and deflections than if the strength and deformation values are relatively uniform.

Procedure II is designed to calculate the allowable bearing stress perpendicular to the grain and uses the formula proposed in ASTM D 245-74 (ASTM 1975b):

$$\text{Allowable bearing stress} = \frac{\left(\text{Average stress at proportional limit}\right) - t_{0.05}S}{1.5}$$

where:

$t_{0.05}$ = 1.833 for 9 degrees of freedom

S = standard deviation

1.5 = adjustment factor for compression perpendicular to the grain.

JOIST BEARING ON WOOD PLATES

METHODS

The test setup for a floor joist supported by a wood plate, the most common method of joist support, is shown in figure 1. Specimens of joists were cut 22¾ inches long and placed in a universal testing machine as previously described. Ten specimens of COM-PLY joists bearing on southern pine plates, and 10 specimens of spruce joists bearing on spruce plates, were tested. The bearing area was 1½ by 1½ inches. The other end of each specimen rested on a steel plate placed on a roller support. Lateral support was provided to prevent the joist section from buckling sideways during loading but not so as to resist vertical movement. The dial gage was placed to record the deformation under load between a point 2 inches above the joist-bearing area and the bottom of the nominal 2 by 4 plate (see fig. 1).

Loads were recorded at increments of 0.005 inch up to a deformation of 0.025 inch and increments of 0.010 inch up to a deformation of 0.125 inch. Failure or ultimate load was considered to be a deformation of 0.125 inch, so the tests were stopped at that point and the loading time was recorded.

The load-deformation curve for each specimen was plotted on graph paper so that the load at proportional limit could be calculated. Proportional limit was calculated by finding the point on the graph at which a 10-percent increase in load resulted in a 20-percent increase in deflection. Engineering tests on strength of materials have defined a point on the load-deformation curve as the "proportional limit." For loads above the proportional limit, large inelastic deformation of the material or fastening system will occur. Such inelastic deformation is undesirable because it remains after the load is removed, which leaves an unacceptable appearance. For some materials and fastening systems it is difficult to find a proportional limit on the load-deformation curve, because the rate of curvature is quite uniform and the curve is smooth without any

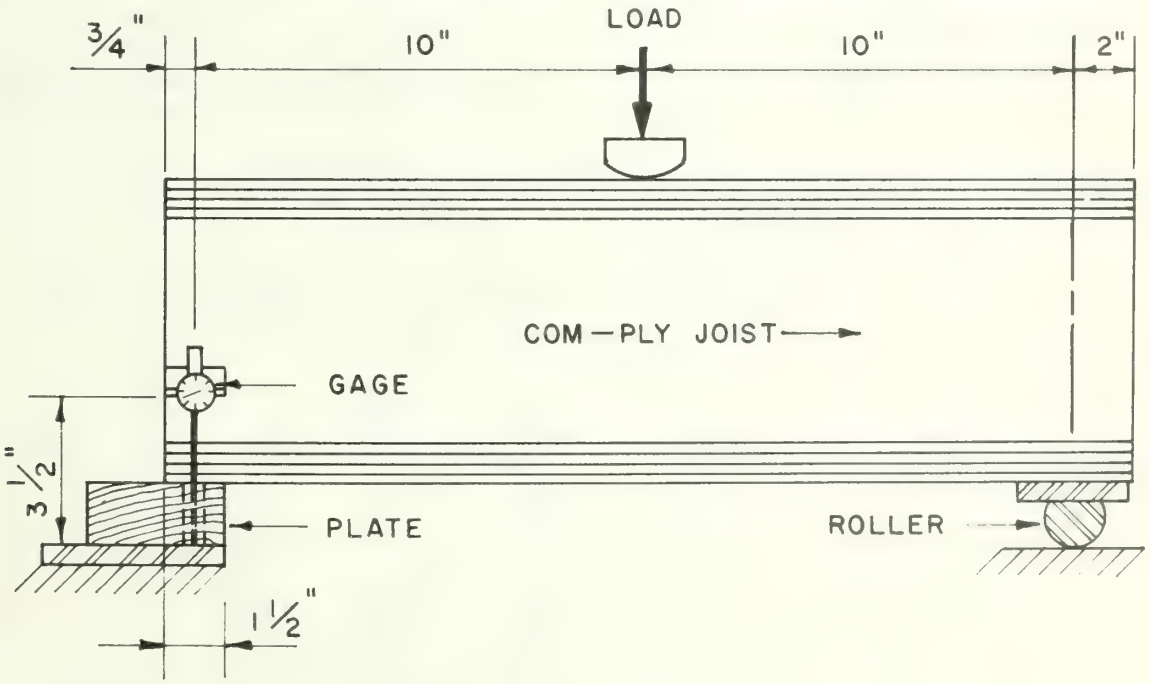

Figure 1.—Joist bearing on plate test.

abrupt changes showing that the system is becoming highly inelastic. Nailed joints in wood often have a load-deformation curve with no well-defined proportional limit load. In unpublished research on strength of nailed joints, Gerald A. Koenigshof (while employed as chief engineer, Timber Engineering Company 1960-65) found that when a 10-percent increase in load caused a 20-percent increase in deformation, any increased loading would cause large inelastic deformations. For loads below that point, the load-deformation curve was essentially elastic and there were relatively small amounts of inelastic deformation. Hence, the point where a 10-percent increase in load results in a 20-percent increase in deformation is a reasonable proportional limit load.

RESULTS

Only the bearing strength values determined by procedure II are reported here, because they closely approximate published design values for spruce while values determined by procedure I do not.

Using procedure II, the allowable bearing stresses were calculated by a formula similar to that proposed in ASTM D 245-74 (ASTM 1975b):

$$\text{Allowable bearing stress} = \frac{\left(\begin{array}{c}\text{Average stress at} \\ \text{proportional limit}\end{array}\right) - t_{0.05}S}{1.5}.$$

For spruce joists,

$$F_{c_1} = \frac{1{,}279 - 1.833\,(262)}{(1.5)\ (2.25)} = 236\ \text{lb/in}^2.$$

For COM-PLY joists,

$$F_{c_1} = \frac{1{,}770 - 1.833\,(228)}{(1.5)\ (2.25)} = 400\ \text{lb/in}^2.$$

In "Design Values for Wood Construction" (NFPA 1977), the design value for spruce–pine–fir is 265 lb/in^2 for compression perpendicular to the grain, and for southern pine it is 405 lb/in^2 for all but the dense grades. The results of the bearing test are shown in table 1.

NOTCHED JOIST BEARING ON WOOD LEDGERS

METHODS

Figure 2 shows the test setup for vertically loading a notched joist on a ledger, a common way to support floor joists when it is desirable to use a flush beam or tail joists over 6 feet long supported by a header. A 1½- by 1½-inch notch was cut into one corner of the specimen and placed downward on a 1½- by 3½-inch piece of southern pine 16 inches long. A hole was bored through this 2×4 at a point about 1½ inches from the bearing area to allow the dial gage stem to measure the movement under load of the joist at a point 2 inches above the top of the 2 × 4 plate with respect to the bottom of the 2 × 4 plate. Thus, the gage length was 3½ inches.

The joist specimens were cut 22¾ inches long to allow a 20-inch span between the center of the bearing area and the center of the roller support. Lateral support was provided to prevent the joist section from buckling sideways but not so as to resist vertical movement. The specimens were loaded as previously described, and all necessary data were recorded.

RESULTS

The test results of the COM-PLY joist bearing capacity on southern pine ledgers are shown in table 2. All COM-PLY specimens in this group failed before deforming 0.125 inch. The mode of failure was

Table 1. -Loads resulting from vertical load tests of 10 COM-PLY joists and 10 spruce joists resting on wood plates

Joist No.	Spruce		COM-PLY	
	Load at proportional limit	Load at 0.125-inch deformation	Load at proportional limit	Load at 0.125-inch deformation
	Pounds			
1	1,225	1,640	2,008	2,860
2	1,425	2,175	1,600	1,600
3	1,125	1,515	1,915	2,325
4	1,625	2,085	1,415	1,670
5	1,000	1,405	1,475	2,175
6	1,688	2,250	1,775	2,430
7	1,388	1,860	2,115	2,115
8	1,000	1,416	1,710	1,710
9	950	1,350	1,760	2,125
10	1,363	2,000	1,925	2,260
Avg.	1,279	1,770	1,770	2,127
SD	262	345	228	387

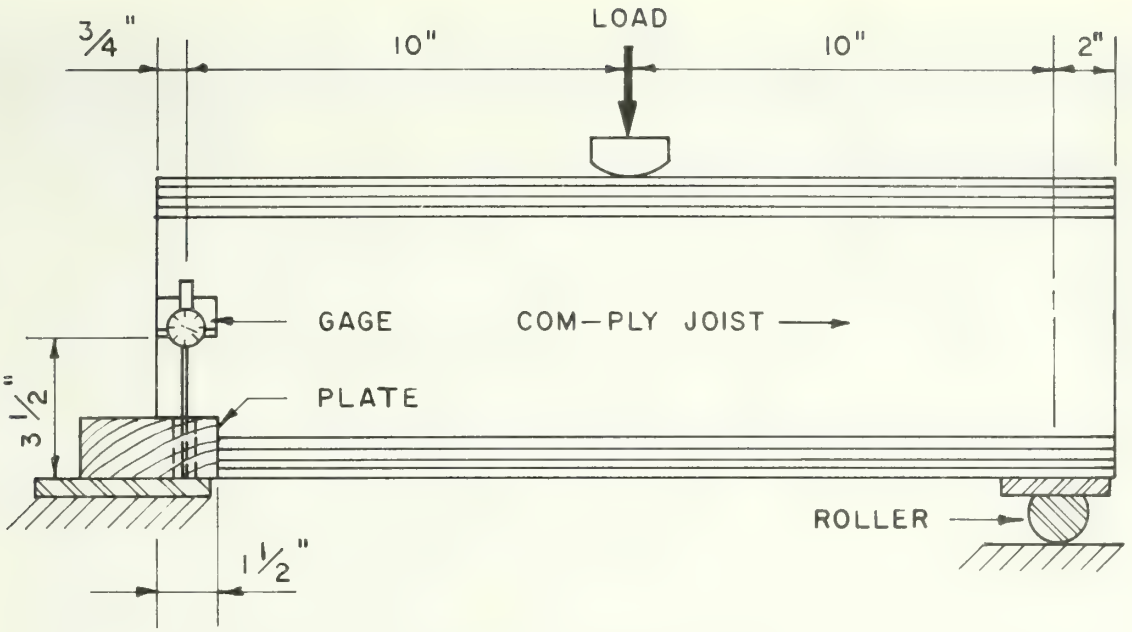

Figure 2.—Notched joist bearing on plate test.

Table 2.—Loads and deformations resulting from vertical load test of notched COM-PLY joist resting on southern pine ledgers

Joist No.	Ultimate load	Deformation at "P" load of 757 (d values)
	Pounds	*Inch*
1	1,875	0.014
2	2,610	.022
3	2,765	.022
4	2,455	.011
5	2,555	.020
6	2,580	.014
7	2,800	.009
8	2,260	.015
9	2,850	.013
10	2,550	.016
Avg.	2,530	.016
SD	288	.004

a fracture in the particleboard core starting at a point at the inside corner of the notch and angling upward at an angle of approximately 45° from the horizontal (fig. 3). The average ultimate load for the 10 specimens was 2,530 pounds and the average standard deviation was 288 pounds. Using procedure I, the calculated adjusted load value per end bearing was 757 pounds.

To calculate the adjusted deformation, load values were plotted on graph paper for each specimen for each corresponding deformation value. Deformation values were taken at the point where the load was 757 pounds. The average deformation for a 757-pound load was 0.0156 inch and the standard deviation was 0.0045 inch. Thus, the adjusted deformation value for this group of specimens, using the formula given previously, was 0.018 inch. The adjusted deformation of 0.018 inch is the maximum deformation that might be expected to occur for a design load of 757 pounds. A deformation of 0.018 is relatively small compared to the large deformation of 0.125 that has been permitted for joist hangers. Therefore, joint deformation under load is within the elastic limit and is not a limiting factor when COM-PLY joists are notched and bear on a ledger.

JOISTS SUPPORTED BY METAL JOIST HANGERS

METHODS

Figure 4 shows the test assembly and setup for loading joists supported by metal joist hangers.

COM-PLY joists were cut into 22-inch lengths and fastened to headers consisting of 16-inch lengths of COM-PLY joists with 18-gage metal joist hangers. The special nails used were those furnished with the hangers by the manufacturer. These assemblies were then placed in a universal testing machine. The header was bolted to a steel vertical support to prevent rotation of the header while loading. A continuous support was provided under the header and positioned to provide an overhang of one-eighth of an inch at the inside edge so as not to allow any vertical restraint of joist movement under load. The dial gage was attached as shown in figure 4, and readings were taken at various loadings as previously described.

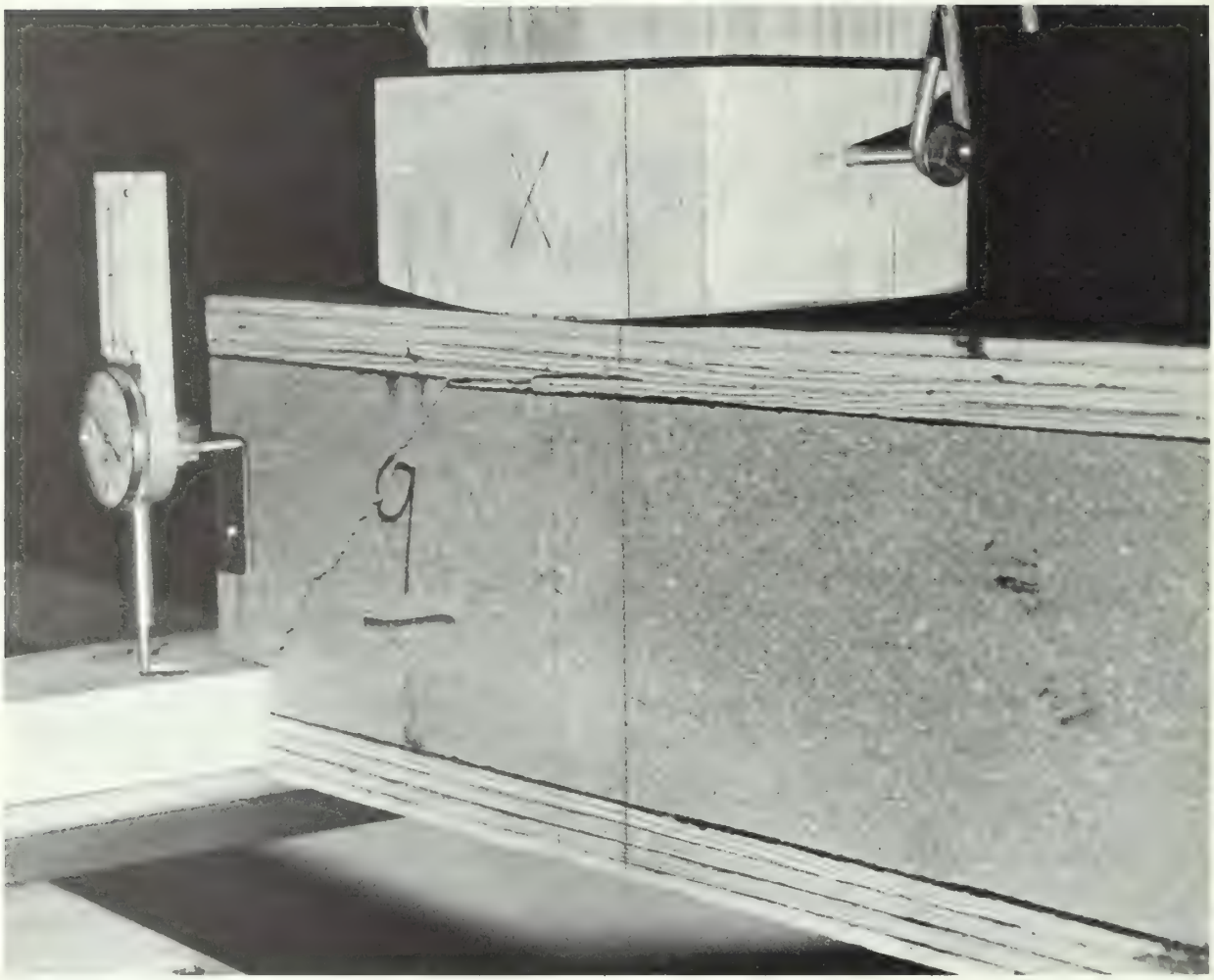

Figure 3.—Fracture of particleboard at ultimate load.

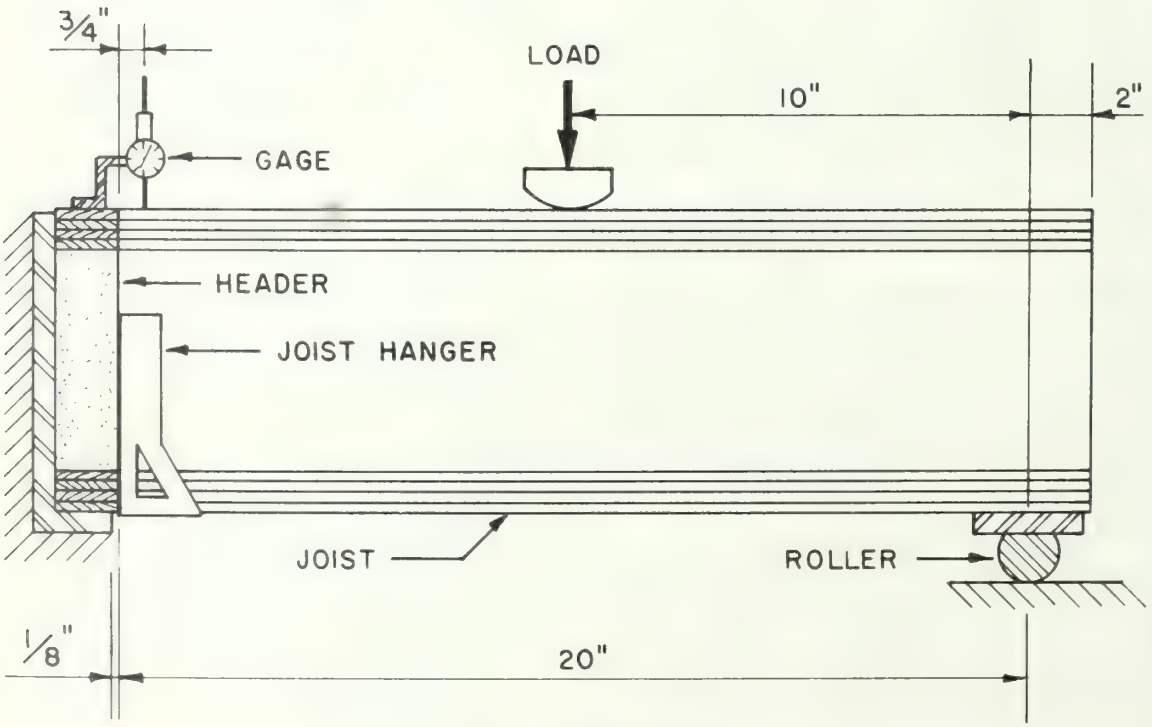

Figure 4.—Joist hanger test.

RESULTS

The results of the vertical load-carrying capacity tests for COM-PLY joists connected to COM-PLY headers with 18-gage metal joist hangers are given in table 3. The average load to produce a deflection of 0.125 inch was 2,394 pounds with a standard deviation of 213 pounds for the sample size of 10 specimens. The ultimate load for the 10 specimens was 3,917 pounds with a standard deviation of 218 pounds.

Applying the strength formula to the test results gives the following value based on the average ultimate load:

$$P = \left[3{,}917 - \frac{(1.833)\ (218)}{\sqrt{10}} - (1.833)\ (218)\right] X \frac{1}{1.5 \times 1.61}$$

P = 1,404 pounds allowable load.

These values indicate that the COM-PLY joist and header fastened with an 18-gage metal joist hanger will safely support a 1,400-pound vertical load. The manufacturer's recommended safe working load for this joist hanger is 900 pounds.

Joint deformation under a 1,400-pound load was interpolated for each specimen from the load-deformation data. These values are shown in table 3. The average joint deformation was 0.052 inch and the standard deviation was 0.011 inch. The computed adjusted value for deformation at this load was computed using the formula:

$$D = 0.052 + \frac{1.833\ (0.011)}{\sqrt{10}}$$

D = 0.058 inch.

This value is less than the 0.125 inch allowable deformation and is within the elastic limit.

Table 3.—Results of vertical load tests for 18-gage metal joist hangers applied to COM-PLY joists

Test No.	Ultimate load	Load at 0.125-inch deformation	Deformation at 1,400-lb. load
	------ *Pounds* -----		*Inch*
1	3,820	2,060	0.073
2	3,700	2,430	.048
3	4,250	2,825	.032
4	3,811	2,280	.058
5	3,700	2,180	.060
6	4,020	2,415	.054
7	4,300	2,425	.049
8	3,780	2,310	.055
9	4,000	2,455	.045
10	3,800	2,575	.048
Avg.	3,918	2,395	.052
SD	217	211	.011

JOISTS SUPPORTED BY NAILS

METHODS

Nails are an approved method for fastening a tail joist to a header in residential construction provided the joist span is not over 6 feet in length, according to the "Manual of Acceptable Practices: a Supplement to the HUD Minimum Property Standards" (HUD 1973).

The test assembly and setup for loading nailed joints between floor joists and headers is shown in figure 5.

To prepare the specimens, a 22-inch length of COM-PLY joist was nailed to a 16-inch piece of COM-PLY joist material with three 16d common nails. These nails were driven through the header and into the end of each joist. A nail was spaced 1½ inches from each narrow edge and one nail midway

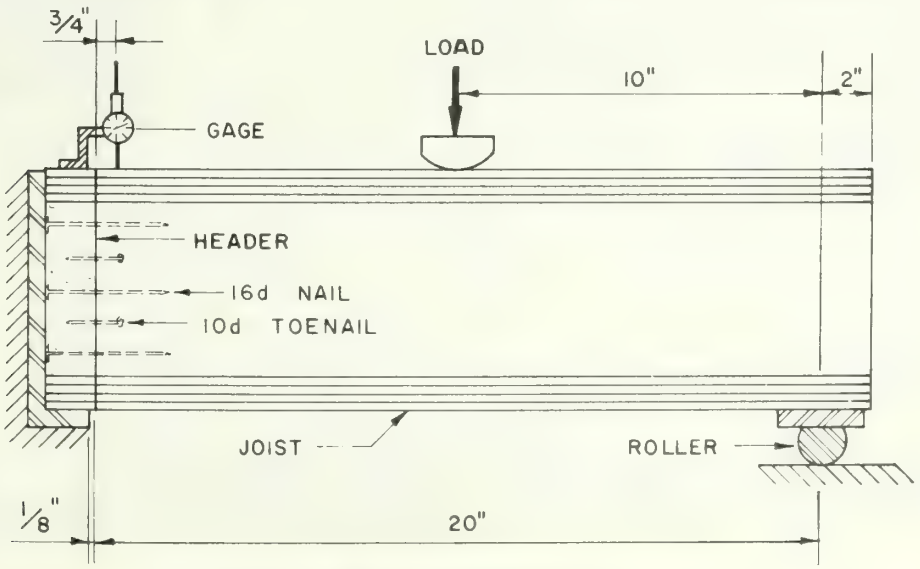

Figure 5.—Joist nailing test.

between the edges. In addition, one 10d nail was toenailed into the wide face of the joist midway between the upper 16d nail and the center 16d nail. Another 10d nail was toenailed into the other wide face of the joist between the lower 16d nail and the center 16d nail. These 10d nails were positioned 1 inch from the end of the joist at a 30° angle to the face of the joist.

Ten specimens were made using COM-PLY joist material, and 10 specimens were made using nominal 2- by 8-inch No. 2 spruce joist material. The specimens were placed in a universal testing machine as shown in figure 6. Loads were recorded at intervals, as previously described, and the ultimate load was recorded.

RESULTS

Table 4 shows the results of the vertical load tests of nailed joints between COM-PLY floor joists and COM-PLY headers and spruce floor joists and spruce headers.

Applying the strength formula to the test results gives an adjusted load of 316 pounds allowable load for the COM-PLY joist and 644 pounds allowable load for the spruce joists. A joist may be supported to a header with nails provided the joist span is 6 feet or less (HUD 1973). Since many new houses are being built using floor joists on 24-inch centers, the design load at the joint would be 300 pounds.

These adjusted load values indicate that the COM-PLY joist and header, fastened with nails, will safely support a 300-pound vertical load.

Table 4 gives the deformations for COM-PLY and spruce joist-to-header joints with a 300-pound load. The computed adjusted value for deformation at this load was calculated using procedure I. The results were 0.010 inch for the COM-PLY joists and 0.005 inch for the spruce joists. The adjusted deformations of 0.010 inch for COM-PLY joists and 0.005 inch for spruce joists are the maximum deformations that might be expected to occur at their corresponding design loads of 316 pounds and 644 pounds. These adjusted deformations are relatively small compared to the large deformation of 0.125 inch that has been permitted for joist hangers. Therefore, joint deformation under load is within the elastic limit and is not a limiting factor when COM-PLY joists are supported by nails only.

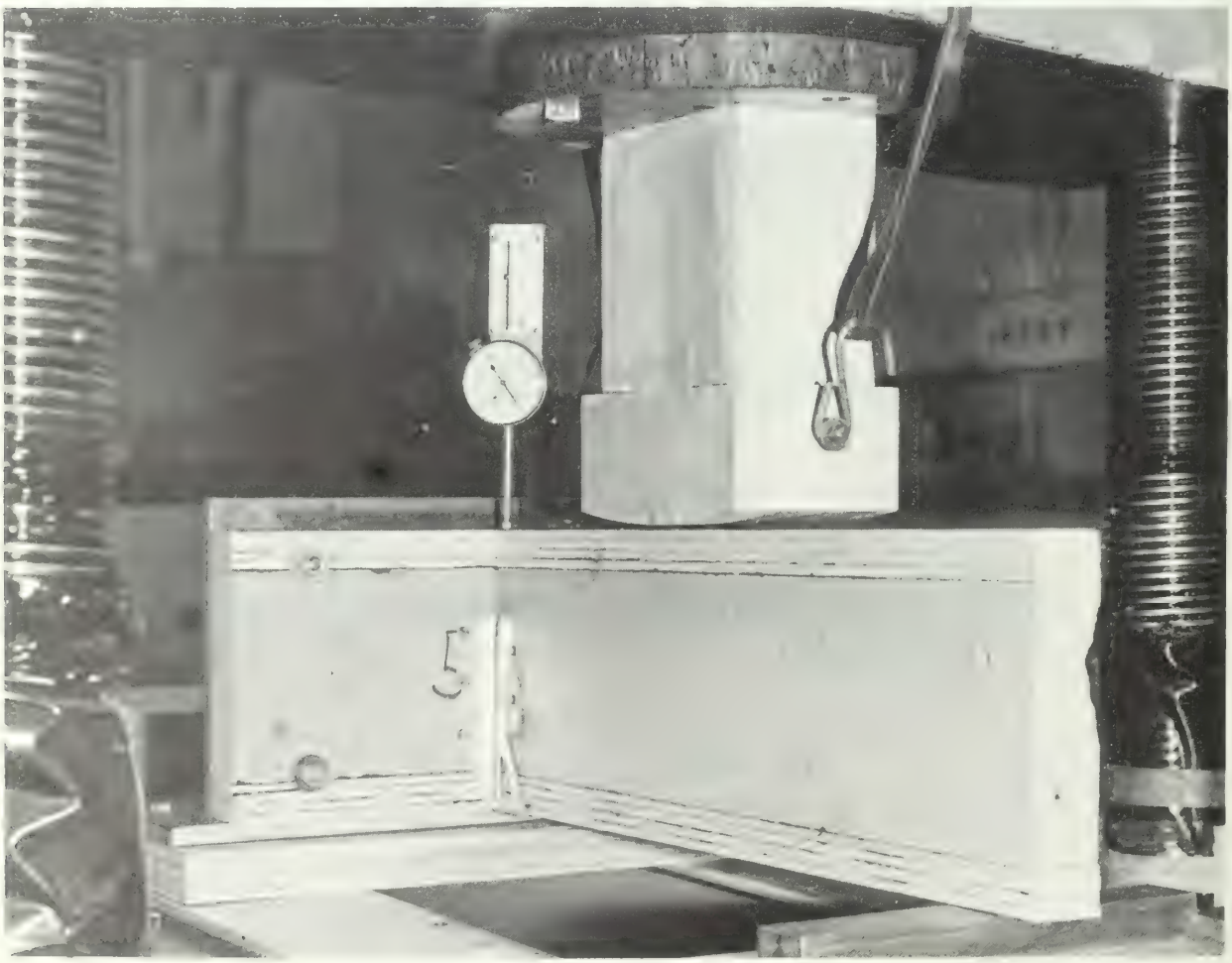

Figure 6.—Setup for testing joint strength of COM-PLY joists.

Table 4.—Loads and deformations from tests of COM-PLY and spruce joist-to-header nailed joints

Joist No.	Spruce			COM-PLY		
	Ultimate load	Load at 0.125 deformation	Deformation at 300-lb load	Ultimate load	Load at 0.125 deformation	Deformation at 300-lb load
	Pounds		*Inch*	*Pounds*		*Inch*
1	1,900	1,225	0.004	970	970	0.009
2	2,000	1,295	.004	935	935	.010
3	2,035	1,275	.006	1,055	1,005	.009
4	2,150	1,325	.004	1,065	1,050	.008
5	1,825	1,325	.005	1,035	960	.011
6	1,875	1,310	.004	1,175	1,140	.008
7	1,740	1,145	.006	1,235	1,235	.006
8	1,925	1,375	.004	885	875	.011
9	2,000	1,250	.006	955	875	.012
10	1,635	1,300	.004	1,000	950	.010
Avg.	1,909	1,283	.005	1,031	999	.009
SD	150	64	.0009	108	115	.0018

CONCLUSIONS

End bearing and joint strength of COM-PLY joists equal or exceed expected design loads for all four of the common methods of support. For two of the support methods, intact joists on wood plates and metal joist hangers, COM-PLY joists performed markedly better than spruce. Performance of notched COM-PLY joists resting on wood ledgers, on the other hand, was no better than adequate. Notching removes some of the design strength and all of the lower cord of veneer of a COM-PLY member and puts most of the stress on the particleboard core. Similarly, performance of COM-PLY joists nailed to COM-PLY headers was less than that of spruce because all of the nails were in the particleboard core, which, in this case, had less nail-holding strength than spruce. However, COM-PLY joists supported in this fashion will support the loads permitted by HUD standards (HUD 1973). Strength of the joint would be greatly increased by use of a metal joist hanger or a particleboard core designed to have superior nail-holding characteristics.

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Experiment Station

Research Paper SE-223

Predicted Total-Tree Biomass of Understory Hardwoods

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Conversion factors: English to metric

Multiply	*by*	*To obtain*
Inches	2.540	centimeters
Feet	.3048	meters
Pounds	.4536	kilograms
Cubic feet	.02832	cubic meters
Pounds per cubic foot	16.02	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor listed above.

July 1981
Southeastern Forest Experiment Station
Asheville, North Carolina

PREDICTED TOTAL-TREE BIOMASS OF UNDERSTORY HARDWOODS

by
Douglas R. Phillips, Mensurationist
Forestry Sciences Laboratory
Athens, Georgia

ABSTRACT.—Prediction equations and tables are presented for estimating total-tree green and dry weights and cubic-foot volumes of wood and bark of understory hardwoods 1 to 5 inches d.b.h. Eleven species common in the Mountains and Piedmont of the Southeast are described. Of these, yellow-poplar and sweetgum were lowest in green weights due to their low densities (specific gravity = 0.359 to 0.459), while the oaks, dogwood, and hickory were high in green weight due to high specific gravities (0.545 to 0.665). Total-tree green weights ranged from 4 to 9 pounds for 1-inch trees to approximately 150 to 280 pounds for 5-inch trees. Total-tree green weight of wood and bark per cubic foot of wood ranged from 65.2 pounds per cubic foot for yellow-poplar in the Mountains in North Carolina to 93.4 pounds per cubic foot for hickory in the Piedmont in Georgia. The proportion of bark expressed as a percentage of dry weight ranged from 14.4 percent for dogwood in the Mountains to 28.7 percent for hickory in the Piedmont.

Keywords: Weight, volume, specific gravity, moisture content, bark content, weight per cubic foot.

INTRODUCTION

Understory hardwoods less than 5 inches d.b.h., long considered an unmerchantable forest component, are now being harvested for fuel and fiber. Improved equipment such as total-tree chippers and, more recently, mobile chippers make such harvesting practical. This new equipment was developed in part to meet the demand for energy wood, but small hardwoods can also be converted into fiber products.

Since understory hardwoods are essentially a new resource to the forest products industry, it is important to know as much about them as possible. Previous research on small hardwoods has been rather limited. Sollins and Anderson (1971) summarized dry-weight yields for some hardwood species. Barker (1974) and Jett and Zobel (1975) examined the papermaking properties of young hardwoods. The physical properties of understory hardwoods were examined by Phillips and McClure (1976), and green- and dry-weight prediction equations were developed by Phillips (1977) and Wartluft (1977).

This Paper presents regression equations and green and dry weight and cubic-foot volume tables for 11 of the most important understory hardwoods in the Piedmont and Mountain regions of the Southeastern United States. These equations improve and thus effectively replace those presented by Phillips (1977). This Paper also describes wood and bark properties and weight per cubic-foot factors for the 11 species. The information in this report makes it possible to inventory existing stands to determine the understory biomass that is available for harvest.

PROCEDURES

FIELD

Sample trees were selected from the understories of mature hardwood and mixed pine–hardwood stands in the Mountains and Piedmont Plateau. Six to eight of the most prevalent species in each physiographic region (as determined from Renewable Resources Evaluation data) were sampled at each of four locations—two in the Mountains in North Carolina, one in the Piedmont in Georgia, and one in the Piedmont in South Carolina (fig. 1).

At each location, approximately 12 trees of each species were sampled. Three trees were taken from each 1-inch d.b.h. class from 1 to 4 inches. Diameter classes were: 1-inch class (1.0 to 1.9 inches), 2-inch class (2.0 to 2.9 inches), 3-inch class (3.0 to 3.9 inches), and the 4-inch class (4.0 to 4.9 inches). Average d.b.h., total height, and age of understory hardwoods in the Mountain and Piedmont regions are given in table 1.

Trees were cut in winter when leaves were absent. Each tree was felled, separated into stem and branches, and weighed. Stems were measured from ground level to the terminal bud. Cross-sectional disks were cut from the stems of most trees at 1 foot, at 4.5 feet, and at 25, 50, 75, and near 100 percent of total-tree height. In some small trees, disks were taken only at 1 foot, 4.5 feet, and 75 percent of total height. Three to nine branch samples were taken from the lower, middle, and upper portions of the crown and processed as a unit to determine wood and bark specific gravity and moisture content of branches.

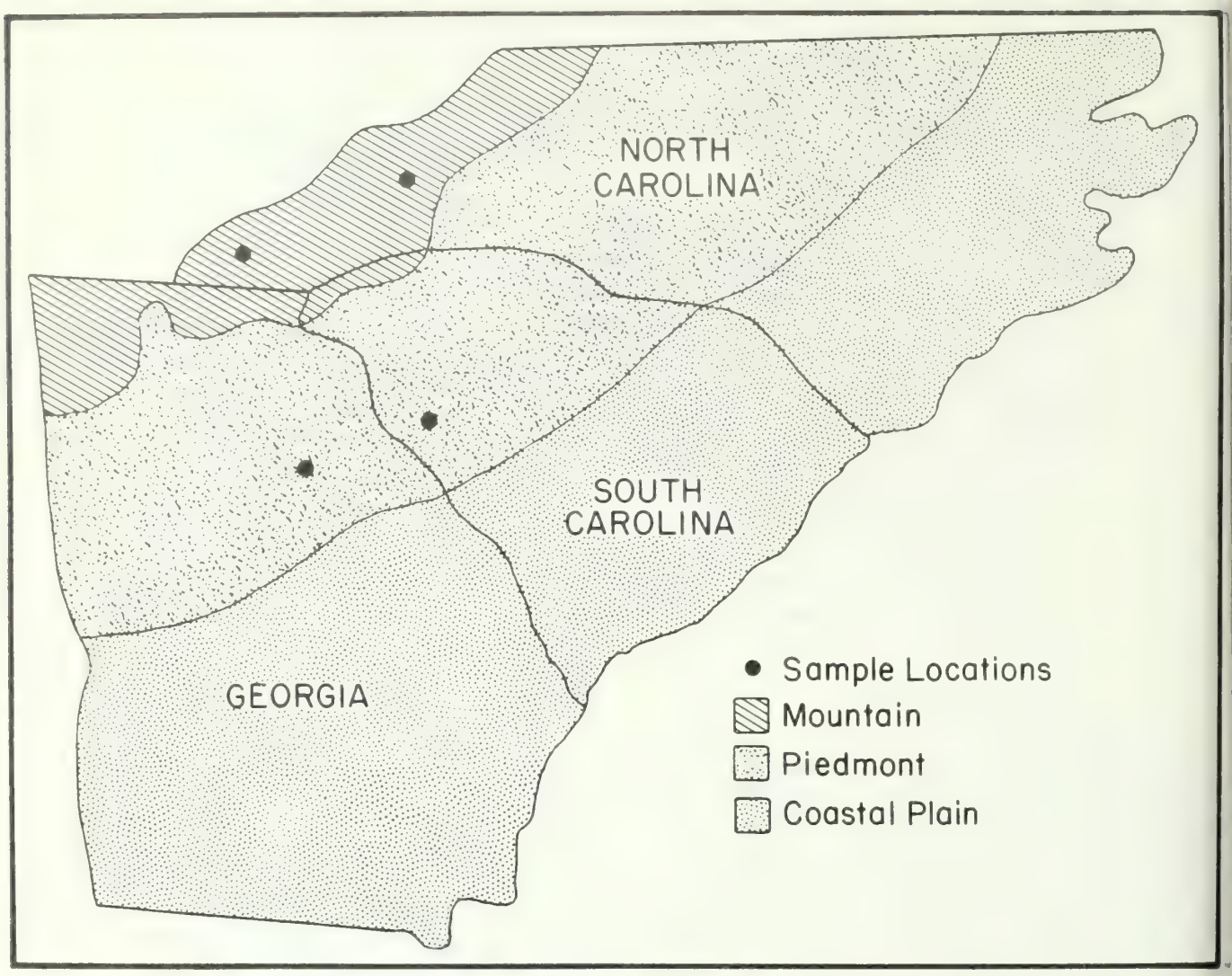

Figure 1.—Physiographic regions and locations where understory hardwoods were sampled.

LABORATORY

In the laboratory, disk samples were weighed green, and diameter outside bark and inside bark were measured. Samples were then soaked for 2 to 3 days before determinations of green volume by displacement. Ovendry weights were determined after samples were dried to a constant weight of 103°C. Specific gravity was computed on a green-volume and ovendry-weight basis. Moisture content was computed on an ovendry-weight basis. Percentage of bark was determined on a dry-weight basis from disk samples. Weighted values for specific gravity, moisture content, and bark percentage were calculated by weighting disk values in proportion to the component they represented.

Dry weights (ovendry weight at 103°C) were calculated from measured green weights and weighted tree moisture contents using the following formula:

$$DWT = (GWT/\ (1 + (MC/100)))$$

where: DWT = dry weight
GWT = green weight of tree or component
MC = weighted tree moisture content in percent.

Green weights per cubic-foot factors were computed from weighted tree specific gravity and moisture content values using the following formula:

$$GWT/FT^3 = (1 + (MC/100)) \times SG \times 62.43$$

where: GWT/FT^3 = green weight per cubic foot
MC = weighted tree moisture content in percent
SG = weighted tree specific gravity.

Dry weights per cubic foot were computed using specific gravity.

$$DWT/FT^3 = SG \times 62.43$$

The cubic volume of wood and bark in the stem, crown, and the total tree were determined by dividing each component's weight by its weight per cubic foot.

STATISTICAL

Standard regression analyses were applied to data on each species at each location and on soft hardwoods (yellow-poplar, sourwood, blackgum, red maple, and sweetgum), hard hardwoods (white oak, chestnut oak, post oak, southern red oak, dogwood, and hickory), and all species combined. Linear equations were developed

Table 1.—D.b.h., total height, and age of understory hardwoods sampled at four locations

Species	Sample trees	D.b.h.		Total height		Age	
		Mean	Range	Mean	Range	Mean	Range
	Number	*Inches*		*Feet*		*Years*	
			MOUNTAINS				
Yellow-poplar	24	3.0	1.1 - 4.9	36.4	21 - 60	18.9	12 - 26
Sourwood	11	3.1	1.5 - 4.9	35.4	23 - 56	31.3	15 - 56
Blackgum	18	3.3	1.6 - 4.9	36.8	21 - 60	37.5	17 - 58
Red maple	24	2.9	1.2 - 4.6	38.0	19 - 59	33.6	12 - 70
White oak	18	2.7	1.1 - 4.9	26.9	14 - 45	37.7	12 - 60
Chestnut oak	24	3.0	1.5 - 4.7	34.0	19 - 51	33.2	12 - 56
Dogwood	24	2.9	1.0 - 4.9	26.0	15 - 42	39.3	17 - 75
Hickory	24	3.0	1.2 - 4.9	34.1	17 - 60	38.7	16 - 57
			PIEDMONT				
Yellow-poplar	24	3.0	1.0 - 4.9	35.1	17 - 53	22.7	6 - 36
Sweetgum	24	3.3	1.3 - 4.8	30.6	15 - 48	26.7	9 - 44
Red maple	23	2.9	1.3 - 4.5	34.4	22 - 49	32.4	14 - 45
White oak	23	2.9	1.2 - 4.9	29.8	15 - 49	33.7	18 - 55
Post oak	12	3.0	1.3 - 4.7	28.6	15 - 43	29.8	20 - 53
Southern red oak	25	3.1	1.1 - 4.6	32.5	13 - 49	30.9	10 - 53
Dogwood	24	3.0	1.1 - 4.7	27.2	16 - 35	35.0	9 - 55
Hickory	22	2.9	1.0 - 4.7	31.4	16 - 48	33.8	13 - 56

sing diameter at breast height squared (D^2) and diameter t breast height squared times total height (D^2Th) as indeendent variables. Plots of residuals across the D^2 and D^2Th scales showed that the variance of Y increased as ree diameters and heights increased. Logarithmic transprmations of the data were performed to make the varinces more homogeneous and thus satisfy this assumpon of regression. The resulting logarithmic equations roved to be better predictors than the linear equations, ut Cunia (1964) cautioned that predicted values on the garithmic scale are slightly biased downward when they re returned to the original scale. Baskerville (1972) proosed a correction factor for natural logarithms which we odified[1] to satisfy common logarithms. This correction ctor was not used, however, since the bias in any given quation was less than 2 percent.

The final forms of the equations were:

$$\text{Log}_{10} Y = \text{Log}_{10} a + b \text{ Log}_{10} (D^2) + \epsilon \quad (1)$$

Thus, $Y = a(D^2)^b \epsilon$

and

$$\text{Log}_{10} Y = \text{Log}_{10} a + b \text{ Log}_{10} (D^2Th) + \epsilon$$

Thus, $Y = a(D^2Th)^b \epsilon$ (2)

here: Y = total-tree weight or volume
a, b = regression coefficients
D^2 = diameter at breast height squared
Th = total-tree height
ϵ = experimental error

[1]Personal communications with H. D. Muse, Mathematical tatistician, USDA Forest Service, Southeastern Forest Experiment tation, Asheville, N.C.

RESULTS

AVERAGE TOTAL-TREE CHARACTERISTICS

The average green weight of 148 soft hardwood trees was 79.0 pounds, compared to 76.3 pounds for 196 hard hardwood trees (table 2). The soft hardwoods weighed more than the hard hardwoods because they were larger. Average diameter and total height were 3.02 inches and 35.2 feet for soft hardwoods and 2.94 inches and 30.3 feet for the hard hardwoods. Volume of the average soft hardwood was 1.372 cubic feet; that for the average hard hardwood was 1.220 cubic feet (table 2).

The higher density of the hard hardwoods shows up in tree dry weights. The average dry weight of hard hardwoods was 45.6 pounds compared to 39.4 pounds for soft hardwoods, even though the soft hardwoods were larger. Hard hardwoods contained more bark (23.7 percent) than soft hardwoods (20.7 percent), and were older (35 years old compared to 28 years old for soft hardwoods).

Total-tree green weight, dry weight, and cubic-foot volume increased steadily with increasing d.b.h. as would be expected (table 2). Bark percentage decreased as tree d.b.h. increased, while average age of the trees increased with increasing d.b.h.

Specific gravity.—Table 3 gives the specific gravity values of wood and bark and wood alone for stems,

Table 2.—Average total-tree green weight, dry weight, cubic volume, dry bark content, and age of understory hard hardwoods and soft hardwoods by d.b.h. class

D.b.h. class[a]	Sample trees	Actual d.b.h.	Total height	Average total-tree				
				Green weight	Dry weight	Volume	Dry bark content	Age
	Number	*Inches*	*Feet*	*--- Pounds ---*		*Cubic feet*	*Percent*	*Years*
				SOFT HARDWOODS[b]				
1	35	1.55	23.0	13.8	6.7	0.241	24.2	20
2	36	2.46	31.3	39.3	19.2	.679	21.3	25
3	39	3.47	38.9	90.9	45.1	1.570	19.4	31
4	38	4.44	46.2	164.4	83.0	2.866	18.3	36
Weighted average	148	3.02	35.2	79.0	39.4	1.372	20.7	28
				HARD HARDWOODS[c]				
1	49	1.54	19.1	13.5	8.0	.219	27.7	24
2	54	2.48	27.6	41.2	24.8	.664	24.2	32
3	46	3.47	35.3	94.3	56.5	1.503	21.7	40
4	47	4.41	40.1	164.6	98.1	2.626	21.0	45
Weighted average	196	2.94	30.3	76.3	45.6	1.220	23.7	35

[a]D.b.h. classes were broken down as follows:
1-inch class = 1.0 to 1.9 inches
2-inch class = 2.0 to 2.9 inches, etc.
[b]The soft hardwood group is made up of yellow-poplar, sweetgum, sourwood, blackgum, and red maple.
[c]The hard hardwood group is made up of white oak, chestnut oak, post oak, southern red oak, dogwood, and hickory.

Table 3.—Specific gravity, moisture content, and bark percentage of understory hardwoods

Species	Number of sample trees	Specific gravity						Moisture content, wood and bark			Bark content		
		Stem		Branches		Total tree							
		Wood	Wood and bark	Wood	Wood and bark	Wood	Wood and bark	Stem	Branches	Total tree	Stem	Branches	Total tree
								Percent					
					MOUNTAINS								
Yellow-poplar	24	0.361	0.359	0.393	0.393	0.365	0.363	127	120	126	20.3	30.3	21.4
Sourwood	11	.510	.467	.481	.459	.505	.466	97	108	99	17.3	26.2	18.8
Blackgum	18	.555	.516	.511	.503	.548	.516	84	100	86	17.6	27.7	19.2
Red maple	24	.501	.510	.487	.501	.499	.508	90	97	91	18.4	25.3	19.7
White oak	18	.627	.592	.581	.565	.621	.589	67	73	68	22.4	33.2	23.9
Chestnut oak	24	.632	.600	.582	.569	.626	.597	64	70	64	25.8	36.2	27.0
Dogwood	24	.621	.576	.609	.574	.618	.576	74	79	76	13.4	16.8	14.4
Hickory	24	.633	.601	.566	.545	.625	.594	56	61	57	27.9	32.9	28.4
					PIEDMONT								
Yellow-poplar	24	.395	.396	.401	.397	.396	.396	137	136	136	21.8	32.2	23.5
Sweetgum	24	.448	.411	.459	.447	.450	.417	117	120	117	22.9	30.6	24.0
Red maple	23	.514	.529	.497	.503	.510	.522	83	85	84	14.9	22.5	16.8
White oak	23	.630	.592	.617	.569	.628	.589	69	69	69	23.4	35.0	24.7
Post oak	12	.652	.574	.607	.548	.647	.570	68	61	67	20.2	38.2	22.2
Southern red oak	25	.607	.612	.618	.606	.609	.612	67	63	67	27.9	30.6	28.3
Dogwood	24	.624	.582	.625	.578	.625	.581	78	88	81	15.1	17.0	15.7
Hickory	22	.671	.651	.632	.590	665	.641	58	66	59	28.1	32.4	28.7

branches, and the total tree of 11 understory hardwood species. Yellow-poplar was lowest in specific gravity for all components (0.36 - 0.40), followed by sweetgum (0.41 - 0.46), and sourwood (0.46 - 0.51). Red maple (0.49 - 0.53) and blackgum (0.50 - 0.56) were intermediate in specific gravity, while the oaks (0.55 - 0.65), dogwood (0.57 - 0.62), and hickory (0.55 - 0.67) were highest. In terms of components, the highest specific gravity was for wood in the stem, while the lowest specific gravity was generally for wood and bark of branches. Red maple and southern red oak bark was generally higher in specific gravity than the wood from the same trees. Yellow-poplar wood had about the same density as yellow-poplar bark. The oaks, hickory, and especially dogwood had bark that was lower in specific gravity than the wood.

Specific gravity by species and component was always higher in the Piedmont than in the Mountains. The largest differences in stem specific gravity were for yellow-poplar (0.361 and 0.359 in the Mountains compared to 0.395 and 0.396 in the Piedmont) and hickory (0.633 and 0.601 in the Mountains compared to 0.671 and 0.651 in the Piedmont). The largest differences in branch specific gravity were for white oak (0.581 and 0.565 in the Mountains compared to 0.617 and 0.569 in the Piedmont) and hickory (0.566 and 0.545 in the Mountains compared to 0.632 and 0.590 in the Piedmont).

Moisture content.—Understory yellow-poplar was higher in moisture content by far than any other species sampled. Average total-tree moisture content (dry-weight basis) was 126 percent for yellow-poplar trees sampled in the Mountains and 136 percent for those sampled in the Piedmont (table 3). Only sweetgum was close to these highs with an average total-tree moisture content of 117 percent. All other species sampled had total-tree moisture contents below 100 percent. Hickory was lowest in moisture content with total-tree values of 57 percent in the Mountains and 59 percent in the Piedmont. Moisture contents for a given species were generally higher in the Piedmont than in the Mountains.

Bark content.—Understory hardwoods have more bark than do larger trees of the same species. Bark content (dry-weight basis) for the 11 species sampled ranged from 14.4 to 28.7 percent of the total tree (table 3). Chestnut oak, southern red oak, and hickory had the highest bark contents (27.0 to 28.7 percent of the total tree), while dogwood had the lowest (14.4 to 15.7 percent) (table 3).

As expected, branches contained a much higher proportion of bark than stems. Branch bark content was highest for post oak, chestnut oak, and white oak (33.2 to 38.2 percent) and lowest for dogwood (16.8 to 17.0 percent).

Bark content of most species was slightly higher in the Piedmont than in the Mountains. The one exception was red maple, which had more bark in the Mountains than in the Piedmont.

Weights per cubic foot.—Green and dry weight per cubic foot factors for understory hardwoods are given by species and geographic region in table 4. The green weight of wood and bark per cubic foot of wood for stems ranged from 63.4 pounds per cubic foot for yellow-poplar in the Mountains to 92.5 pounds per cubic foot for hickory in the Piedmont. The values for branches ranged from 54.2 pounds per cubic foot for yellow-poplar in the Mountains to 103.5 pounds per cubic foot for post oak in the Piedmont. These weight per cubic foot values for small understory trees are higher than reported values for larger trees (Clark and others 1980a, 1980b). This difference is predictable, since small trees contain a higher proportion of bark than larger ones.

The green and dry weights of wood and bark per cubic foot of wood and bark showed trends similar to the weight-volume ratios just discussed. The lowest values were for yellow-poplar, especially in the Mountains, and the highest values were for southern red oak, dogwood, and hickory in the Piedmont. The weights of wood and bark per cubic foot of wood and bark for understory trees are similar to values reported for larger overstory trees (Jett and Zobel 1975).

REGRESSION EQUATIONS

Regression equations for predicting total-tree green weight, dry weight, and cubic-foot volume of understory hardwoods are presented in tables 5 through 12 in the Appendix. Tables 5 through 8 contain equations for predicting total-tree green weight, dry weight, cubic-foot volume of wood and bark, and cubic-foot volume of wood alone for species in the Mountains, in the Piedmont, and in both regions combined when both d.b.h. and total height are known. Tables 9 through 12 present equations for predicting the same dependent variables when only tree diameter is known.

Coefficients of determination (R^2) for the equations ranged from 0.93 to 0.99, indicating strong relationships between tree weights and volumes and the independent variables (D^2Th and D^2). Standard errors of the estimate ($S_{y.x}$) show the relative variation between equations and are useful in computing confidence intervals about regression lines. Variation in $S_{y.x}$ generally increased and R^2 values decreased as data were combined, first across the two locations and then across species and locations. The sample mean of x ($\bar{x}$) and the corrected sums of squares for x ($\Sigma(x-\bar{x})^2$) are also given for each equation so confidence limits can be computed for the lognormal means using a procedure by Land (1972) and described on page 6. Prediction equations for soft hardwoods and hard hardwoods did not differ significantly by region, so only the overall combined equations are reported. These combined equations are provided for general use where species breakdowns are not practical or desired.

TOTAL-TREE GREEN-WEIGHT TABLES

Predicted total-tree green weights of 11 understory hardwood species, by d.b.h. classes from 1 to 6 inches and by total-tree height classes from 15 to 60 feet, are presented in Appendix tables 13 through 26. Predictions were extended to 6 inches (1-inch beyond the range of the data) for those who may want to use the data to this level.

Table 4.—Green and dry weight per cubic-foot factors for understory hardwoods

Species	Green weight of wood and bark per cubic foot of wood			Green weight of wood and bark per foot of wood and bark[a]			Dry weight of wood and bark per cubic foot of wood and bark[a]		
	Stem	Branches	Total tree	Stem	Branches	Total tree	Stem	Branches	Total tree
	Pounds/cubic foot								
MOUNTAINS									
Yellow-poplar	63.4	84.2	65.2	50.9	53.3	51.2	22.4	24.5	22.7
Sourwood	76.6	94.5	79.4	57.6	59.4	58.0	29.2	28.6	29.1
Blackgum	76.6	99.5	80.0	59.7	62.1	60.1	32.2	31.4	32.2
Red maple	72.2	75.9	72.7	60.1	61.4	60.4	31.8	31.3	31.7
White oak	81.5	88.8	82.4	61.5	61.0	61.5	34.4	36.9	36.8
Chestnut oak	86.9	100.8	88.2	61.3	60.4	61.2	37.5	35.5	37.2
Dogwood	77.6	81.6	78.7	62.5	64.2	63.1	36.0	35.8	36.0
Hickory	85.8	86.8	85.9	58.5	54.9	58.1	37.5	34.0	37.1
PIEDMONT									
Yellow-poplar	74.8	86.0	76.4	58.4	58.2	58.3	24.7	24.8	24.7
Sweetgum	80.1	91.0	81.5	55.5	61.0	56.4	25.6	27.9	26.0
Red maple	70.5	77.4	72.3	60.2	58.1	59.7	33.0	31.4	32.6
White oak	86.1	94.2	87.0	62.2	60.2	62.0	37.0	35.5	36.8
Post oak	91.8	103.5	92.9	60.1	56.0	59.7	35.8	34.2	35.6
Southern red oak	92.0	87.9	91.3	64.0	61.9	63.8	38.2	37.8	38.2
Dogwood	86.9	83.8	85.9	64.7	68.0	65.7	36.6	36.1	36.3
Hickory	92.5	97.2	93.4	64.1	61.0	63.6	40.7	36.9	40.0

[a]Wood and bark cubic volume was determined by dividing wood and bark weight by wood and bark weight per cubic foot and thus does not include air space in the bark fissures.

In many cases (for example, for dogwood, sourwood, and possibly other species), predictions beyond 6 inches may be used, since equations for trees larger than 6 inches are not available. These tables were generated from equations in Appendix table 5. The most general equations were used, and thus the tables should have broad application across both geographic regions examined. Tables 13 through 23 give predicted weights of individual species. Tables 24 through 26 are general overall equations for soft hardwoods, hard hardwoods, and all hardwoods combined.

Predicted total-tree green weights of understory hardwoods based on d.b.h. alone (D^2) are given in table 27. Weights are given by 1-inch diameter classes from 1 to 6 inches for each species in both the Mountain and Piedmont regions and for soft hardwoods and hard hardwoods. Differences between species are minimized when a single variable is used. The difference between soft and hard hardwoods is also small because soft hardwoods of a given diameter tend to be taller than hard hardwoods of the same diameter (see table 1).

The equations and yield tables in this report are directly applicable only to understory hardwoods in the Mountains and Piedmont of the Southeastern United States. Caution should be used when the equations are used in different regions of the country.

COMPUTATION OF CONFIDENCE LIMITS

Tables 5 through 12 contain the standard errors of the estimate, the sample mean of x and the corrected sums of squares for x for each equation in Log_{10} form. These statistics can be used to calculate approximate confidence limits in pounds or cubic feet by using a modification of Cox's formula (Land 1972) for estimating confidence limits for lognormal means:

$$Y_{U,L} = 10^{\text{Log } Y \pm Z \sqrt{S^2_{y \cdot x}\left[\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right] + \frac{S^4_{y \cdot x}}{2(n+1)}}}$$

where: $Y_{U,L}$ = upper and lower limits for Y

Y = predicted weight or volume

Z = value from the standard normal table for appropriate confidence level

$S_{y.x}$ = standard error of estimate for prediction equation

n = number of observations used to develop the equation

$\bar{x}$ = sample mean of log x—(from table of equations)

$\Sigma(x-\bar{x})^2$ = corrected sums of squares for log x—(from table of equations)

x = value of independent variable in $\log_{10}$ form.

Cox's method of approximation sufficiently estimates actual confidence limits when applied to samples with small variances, as occur in the total-tree weight and volume equations in this Paper.

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Appendix

Table 5.—Regression equations and associated statistics for predicting total-tree green weight of understory hardwoods based on diameter squared times total height (D^2Th)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)[a]	Sample mean of x ($\bar{x}$)[a]	Corrected sums of squares for x ($\Sigma(x-\bar{x})^2$)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 0.30860 (D^2Th)^{0.89369}$	0.046	2.409	5.867	0.99
Sourwood	11	$Y = 0.31997 (D^2Th)^{0.93059}$	.046	2.449	2.025	.99
Blackgum	18	$Y = 0.52910 (D^2Th)^{0.83757}$	.086	2.554	2.971	.95
Red maple	24	$Y = 0.40005 (D^2Th)^{0.89596}$	.054	2.421	5.659	.99
White oak	18	$Y = 0.43637 (D^2Th)^{0.87624}$	.042	2.196	4.533	.99
Chestnut oak	24	$Y = 0.44567 (D^2Th)^{0.87324}$	.040	2.410	4.859	.99
Dogwood	24	$Y = 0.58180 (D^2Th)^{0.86365}$	.062	2.247	6.060	.98
Hickory	24	$Y = 0.38728 (D^2Th)^{0.89089}$	.041	2.401	5.782	.99
		PIEDMONT				
Yellow-poplar	24	$Y = 0.37031 (D^2Th)^{0.89090}$	.050	2.404	7.075	.99
Sweetgum	24	$Y = 0.34061 (D^2Th)^{0.88255}$	.082	2.353	5.567	.97
Red maple	23	$Y = 0.32119 (D^2Th)^{0.93057}$	.054	2.396	4.021	.98
White oak	23	$Y = 0.50057 (D^2Th)^{0.84452}$	.084	2.300	5.678	.96
Post oak	12	$Y = 0.45540 (D^2Th)^{0.86019}$	.043	2.341	2.393	.99
Southern red oak	25	$Y = 0.55167 (D^2Th)^{0.84140}$	.079	2.400	6.181	.97
Dogwood	24	$Y = 0.37500 (D^2Th)^{0.94932}$	.050	2.300	4.794	.98
Hickory	22	$Y = 0.47978 (D^2Th)^{0.86816}$	.076	2.324	5.603	.97
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 0.33899 (D^2Th)^{0.89180}$	.060	2.406	12.942	.98
Red maple	47	$Y = 0.36353 (D^2Th)^{0.91070}$	.053	2.409	9.687	.98
White oak	41	$Y = 0.46590 (D^2Th)^{0.86130}$	.062	2.254	10.320	.98
Dogwood	48	$Y = 0.48010 (D^2Th)^{0.90174}$	.062	2.274	10.889	.98
Hickory	46	$Y = 0.43736 (D^2Th)^{0.87668}$	.062	2.364	11.453	.98
Soft hardwoods	148	$Y = 0.35379 (D^2Th)^{0.89767}$	.074	2.420	33.651	.97
Hard hardwoods	196	$Y = 0.47221 (D^2Th)^{0.87186}$	.071	2.328	46.815	.97
All hardwoods	344	$Y = 0.43247 (D^2Th)^{0.87655}$	.079	2.367	81.178	.97

[a] In $\log_{10}$ form.

Table 6—Regression equations and associated statistics for predicting total-tree dry weight of understory hardwoods based on diameter squared times total height (D^2Th)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)[a]	Sample mean of x ($\bar{x}$)[a]	Corrected sums of squares for x ($\Sigma(x-\bar{x})^2$)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 0.13341\ (D^2Th)^{0.89858}$	0.058	2.409	5.867	0.98
Sourwood	11	$Y = 0.14272\ (D^2Th)^{0.95161}$	.040	2.449	2.025	.99
Blackgum	18	$Y = 0.26845\ (D^2Th)^{0.84961}$	.098	2.554	2.971	.93
Red maple	24	$Y = 0.18073\ (D^2Th)^{0.92236}$	.057	2.421	5.659	.98
White oak	18	$Y = 0.26024\ (D^2Th)^{0.87654}$	.040	2.196	4.533	.99
Chestnut oak	24	$Y = 0.27440\ (D^2Th)^{0.87051}$	.033	2.410	4.859	.99
Dogwood	24	$Y = 0.32104\ (D^2Th)^{0.88[illegible]}$	.062	2.247	6.060	.98
Hickory	24	$Y = 0.24818\ (D^2Th)^{0.89025}$	.042	2.401	5.782	.99
		PIEDMONT				
Yellow-poplar	24	$Y = 0.13868\ (D^2Th)^{0.91334}$	.051	2.404	7.075	.99
Sweetgum	24	$Y = 0.16560\ (D^2Th)^{0.87099}$	.081	2.353	5.567	.97
Red maple	23	$Y = 0.16183\ (D^2Th)^{0.94488}$	.059	2.396	4.021	.98
White oak	23	$Y = 0.28514\ (D^2Th)^{0.85215}$	.089	2.300	5.678	.96
Post oak	12	$Y = 0.25516\ (D^2Th)^{0.87[illegible]}$	.047	2.341	2.393	.99
Southern red oak	25	$Y = 0.34808\ (D^2Th)^{0.83893}$	.075	2.400	6.181	.97
Dogwood	24	$Y = 0.20656\ (D^2Th)^{0.95000}$	061	2.300	4.794	.98
Hickory	22	$Y = 0.29434\ (D^2Th)^{0.87271}$	.071	2.324	5.603	.98
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 0.13570\ (D^2Th)^{0.90638}$	.060	2.406	12.942	.98
Red maple	47	$Y = 0.17293\ (D^2Th)^{0.93153}$	.057	2.409	9.687	.98
White oak	41	$Y = 0.27138\ (D^2Th)^{0.86538}$	.065	2.254	10.320	.98
Dogwood	48	$Y = 0.26530\ (D^2Th)^{0.90479}$	.063	2.274	10.889	.98
Hickory	46	$Y = 0.27356\ (D^2Th)^{0.87912}$	.059	2.364	11.453	.98
Soft hardwoods	148	$Y = 0.15630\ (D^2Th)^{0.91501}$	.103	2.420	33.651	.95
Hard hardwoods	196	$Y = 0.27591\ (D^2Th)^{0.87600}$	.064	2.328	46.815	.98
All hardwoods	344	$Y = 0.23516\ (D^2Th)^{0.87762}$	.113	2.367	81.178	.94

[a] In $\log_{10}$ form.

Table 7.—Regression equations and associated statistics for predicting total-tree cubic volume of understory hardwoods based on diameter squared times total height (D^2Th)

Species	Number trees sampled (N)	Regression equation	Standard error of estimates ($S_{y.x}$)[a]	Sample mean of x ($\bar{x}$)[a]	Corrected sums of squares for x ($\Sigma(x - \bar{x})^2$)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 0.00678 (D^2Th)^{0.87286}$	0.044	2.409	5.867	0.99
Sourwood	11	$Y = 0.00527 (D^2Th)^{0.93907}$	.036	2.449	2.025	.99
Blackgum	18	$Y = 0.00945 (D^2Th)^{0.82658}$	.082	2.554	2.971	.95
Red maple	24	$Y = 0.00651 (D^2Th)^{0.89940}$	.044	2.421	5.659	.99
White oak	18	$Y = 0.00777 (D^2Th)^{0.85866}$	.043	2.196	4.533	.99
Chestnut oak	24	$Y = 0.00733 (D^2Th)^{0.87194}$	.037	2.410	4.859	.99
Dogwood	24	$Y = 0.00895 (D^2Th)^{0.86951}$	.059	2.247	6.060	.98
Hickory	24	$Y = 0.00735 (D^2Th)^{0.87356}$	.049	2.401	5.782	.99
		PIEDMONT				
Yellow-poplar	24	$Y = 0.00603 (D^2Th)^{0.90075}$	.042	2.404	7.075	.99
Sweetgum	24	$Y = 0.00648 (D^2Th)^{0.86877}$	.065	2.353	5.567	.98
Red maple	23	$Y = 0.00512 (D^2Th)^{0.93968}$	.056	2.396	4.021	.98
White oak	23	$Y = 0.00839 (D^2Th)^{0.83759}$	.079	2.300	5.678	.97
Post oak	12	$Y = 0.00889 (D^2Th)^{0.83218}$	.035	2.341	2.393	.99
Southern red oak	25	$Y = 0.00954 (D^2Th)^{0.82383}$	.076	2.400	6.181	.97
Dogwood	24	$Y = 0.00546 (D^2Th)^{0.95798}$	.061	2.300	4.794	.98
Hickory	22	$Y = 0.00787 (D^2Th)^{0.86038}$	.067	2.324	5.603	.98
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 0.00635 (D^2Th)^{0.83802}$	.048	2.406	12.942	.99
Red maple	47	$Y = 0.00587 (D^2Th)^{0.91636}$	.050	2.409	9.687	.99
White oak	41	$Y = 0.00804 (D^2Th)^{0.84940}$	.059	2.254	10.320	.98
Dogwood	48	$Y = 0.00722 (D^2Th)^{0.90780}$	.063	2.274	10.889	.98
Hickory	46	$Y = 0.00760 (D^2Th)^{0.86717}$	.054	2.364	11.453	.99
Soft hardwoods	148	$Y = 0.00632 (D^2Th)^{0.89344}$	.061	2.420	33.651	.98
Hard hardwoods	196	$Y = 0.00787 (D^2Th)^{0.86537}$	.064	2.328	46.815	.98
All hardwoods	344	$Y = 0.00729 (D^2Th)^{0.87440}$	.064	2.367	81.178	.98

[a] In $\log_{10}$ form.

Table 8.—Regression equations and associated statistics for predicting the cubic volume of wood in the total tree for understory hardwoods based on diameter squared times total height (D^2Th)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)[a]	Sample mean of x ($\bar{X}$)	Corrected sums of squares for x ($\Sigma(x-\bar{x})^2$)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 0.00420\ (D^2Th)^{0.91502}$	0.036	2.409	5.867	0.99
Sourwood	11	$Y = 0.00431\ (D^2Th)^{0.91650}$	.034	2.449	2.025	.99
Blackgum	18	$Y = 0.00651\ (D^2Th)^{0.84033}$	.067	2.554	2.971	.97
Red maple	24	$Y = 0.00506\ (D^2Th)^{0.91027}$	.049	2.421	5.659	.99
White oak	18	$Y = 0.00472\ (D^2Th)^{0.89935}$	.056	2.196	4.533	.99
Chestnut oak	24	$Y = 0.00441\ (D^2Th)^{0.89612}$	.042	2.410	4.859	.99
Dogwood	24	$Y = 0.00710\ (D^2Th)^{0.87000}$	.072	2.247	6.060	.98
Hickory	24	$Y = 0.00422\ (D^2Th)^{0.90203}$	.047	2.401	5.782	.99
		PIEDMONT				
Yellow-poplar	24	$Y = 0.00405\ (D^2Th)^{0.92507}$	.052	2.404	7.075	.99
Sweetgum	24	$Y = 0.00414\ (D^2Th)^{[illegible]}$	.093	2.353	5.567	.96
Red maple	23	$Y = 0.00351\ (D^2Th)^{0.97130}$	.063	2.396	4.021	.98
White oak	23	$Y = 0.00458\ (D^2Th)^{0.88804}$	.061	2.300	5.678	.98
Post oak	12	$Y = 0.00362\ (D^2Th)^{0.92006}$	.029	2.341	2.393	.99
Southern red oak	25	$Y = 0.00466\ (D^2Th)^{0.83415}$	.046	2.400	6.181	.99
Dogwood	24	$Y = 0.00474\ (D^2Th)^{0.93312}$	.055	2.300	4.794	.98
Hickory	22	$Y = 0.00402\ (D^2Th)^{0.91208}$	.066	2.324	5.603	.98
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 0.00411\ (D^2Th)^{0.92046}$	.044	2.406	12.942	.99
Red maple	47	$Y = 0.00433\ (D^2Th)^{0.93599}$	.057	2.409	9.687	.98
White oak	41	$Y = 0.00473\ (D^2Th)^{0.88911}$	.060	2.254	10.320	.98
Dogwood	48	$Y = 0.00599\ (D^2Th)^{0.89600}$	.066	2.274	10.889	.98
Hickory	46	$Y = 0.00412\ (D^2Th)^{0.90677}$	.056	2.364	11.453	.98
Soft hardwoods	148	$Y = 0.00430\ (D^2Th)^{0.91427}$	.078	2.420	33.651	.97
Hard hardwoods	196	$Y = 0.00496\ (D^2Th)^{0.88808}$	.080	2.328	46.815	.97
All hardwoods	344	$Y = 0.00468\ (D^2Th)^{0.89912}$	.079	2.367	81.178	.97

[a] In $\log_{10}$ form.

Table 9.—Regression equations and associated statistics for predicting total-tree green weight of understory hardwoods based on diameter squared (D^2)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)[a]	Sample mean of x ($\bar{x}$)	Corrected sums of squares for x ($\Sigma(x-\bar{x})^2$)	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 4.97092\ (D^2)^{1.20000}$	0.061	0.869	3.226	0.98
Sourwood	11	$Y = 4.97417\ (D^2)^{1.18675}$	.076	.961	1.222	.97
Blackgum	18	$Y = 5.01543\ (D^2)^{1.16009}$	.083	1.002	1.553	.95
Red maple	24	$Y = 5.47926\ (D^2)^{1.20022}$	.057	.860	3.148	.98
White oak	18	$Y = 4.17904\ (D^2)^{1.19546}$	.062	.787	2.384	.98
Chestnut oak	24	$Y = 4.81741\ (D^2)^{1.20025}$	.052	.892	2.555	.98
Dogwood	24	$Y = 5.99504\ (D^2)^{1.09345}$	.063	.848	3.780	.98
Hickory	24	$Y = 4.44954\ (D^2)^{1.20990}$	.079	.892	3.066	.97
		PIEDMONT				
Yellow-poplar	24	$Y = 4.50088\ (D^2)^{1.20035}$	.046	.880	3.904	.99
Sweetgum	24	$Y = 3.51823\ (D^2)^{1.19147}$	.102	.888	2.988	.95
Red maple	23	$Y = 5.00668\ (D^2)^{1.19140}$	.058	.870	2.446	.98
White oak	23	$Y = 4.36406\ (D^2)^{1.17708}$	.106	.851	2.870	.94
Post oak	12	$Y = 3.86920\ (D^2)^{1.19942}$	.062	.904	1.217	.98
Southern red oak	25	$Y = 4.81192\ (D^2)^{1.18368}$	.077	.911	3.130	.97
Dogwood	24	$Y = 4.94325\ (D^2)^{1.21168}$	.057	.878	2.944	.98
Hickory	22	$Y = 4.91584\ (D^2)^{1.18639}$	.062	.849	3.027	.98
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 4.21906\ (D^2)^{1.20158}$	.059	.875	5.295	.98
Red maple	47	$Y = 5.24817\ (D^2)^{1.19535}$	.061	.865	5.595	.98
White oak	41	$Y = 4.23067\ (D^2)^{1.19489}$	.079	.823	5.295	.97
Dogwood	48	$Y = 5.52430\ (D^2)^{1.14618}$	.063	.863	6.734	.98
Hickory	46	$Y = 4.69064\ (D^2)^{1.19640}$	.071	.871	6.114	.98
Soft hardwoods	148	$Y = 4.52670\ (D^2)^{1.19344}$	.090	.892	18.763	.96
Hard hardwoods	196	$Y = 4.69848\ (D^2)^{1.18743}$	.073	.896	25.206	.97
All hardwoods	344	$Y = 4.62896\ (D^2)^{1.18950}$	.081	.879	44.016	.97

[a] In $\log_{10}$ form.

Table 10.--Regression equations and associated statistics for predicting total-tree dry weight of understory hardwoods based on diameter squared (D^2)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)[a]	Sample mean of x ($\bar{x}$)[a]	Corrected sums of squares for x ($\Sigma(x-\bar{x})^2$)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 1.74524 (D^2)^{1.20610}$	0.073	0.869	3.226	0.98
Sourwood	11	$Y = 2.37722 (D^2)^{1.21022}$	.081	.961	1.222	.97
Blackgum	18	$Y = 2.56795 (D^2)^{1.18685}$	.083	1.002	1.553	.95
Red maple	24	$Y = 2.67148 (D)^{2\ 1.23601}$	.060	.860	3.148	.98
White oak	18	$Y = 2.50124 (D^2)^{1.19431}$	.065	.787	2.384	.98
Chestnut oak	24	$Y = 2.93819 (D^2)^{1.19746}$	.044	.892	2.555	.99
Dogwood	24	$Y = 3.37156 (D^2)^{1.10056}$	.065	.848	3.780	.98
Hickory	24	$Y = 2.86238 (D^2)^{1.20634}$	.085	.892	3.066	.96
		PIEDMONT				
Yellow-poplar	24	$Y = 1.79951 (D^2)^{1.22938}$	.052	.880	3.904	.99
Sweetgum	24	$Y = 1.67422 (D^2)^{1.17677}$	.102	.888	2.988	.95
Red maple	23	$Y = 2.62288 (D^2)^{1.21132}$	.059	.870	2.446	.98
White oak	23	$Y = 2.54413 (D^2)^{1.18590}$	.113	.851	2.870	.94
Post oak	12	$Y = 2.23774 (D^2)^{1.21527}$	.067	.904	1.217	.98
Southern red oak	25	$Y = 2.96156 (D^2)^{1.17059}$	.072	.911	3.130	.97
Dogwood	24	$Y = 2.73676 (D^2)^{1.21095}$	.064	.878	2.944	.98
Hickory	22	$Y = 3.06011 (D^2)^{1.19138}$	.060	.849	3.027	.98
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 1.76621 (D^2)^{1.21948}$	.064	.875	5.295	.98
Red maple	47	$Y = 2.64377 (D^2)^{1.22458}$	.060	.865	5.595	.98
White oak	41	$Y = 2.49773 (D^2)^{1.19895}$	.085	.823	5.295	.96
Dogwood	48	$Y = 3.08355 (D^2)^{1.14915}$	.067	.863	6.734	.98
Hickory	46	$Y = 2.96561 (D^2)^{1.19764}$	.073	.871	6.114	.97
Soft hardwoods	148	$Y = 2.10553 (D^2)^{1.21538}$	.117	.892	18.763	.93
Hard hardwoods	196	$Y = 2.79822 (D^2)^{1.18897}$	.075	.869	25.206	.97
All hardwoods	344	$Y = 2.50008 (D^2)^{1.19572}$	.108	.879	44.016	.94

[a] In $\log_{10}$ form.

Table 11—Regression equations and associated statistics for predicting the cubic volume of wood and bark in the total tree for understory hardwoods based on diameter squared (D^2)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)	Sample mean of x ($\bar{G}$)[a]	Corrected sums of squares for x (ΣG^2)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 0.08237\ (D^2)^{1.17182}$	0.061	0.869	3.226	0.98
Sourwood	11	$Y = 0.08159\ (D^2)^{1.16}$	.070	.961	1.222	.98
Blackgum	18	$Y = 0.08752\ (D^2)^{1.16}$	.083	1.002	1.553	.95
Red maple	24	$Y = 0.09032\ (D^2)^{1.20343}$	.053	.860	3.148	.99
White oak	18	$Y = 0.07110\ (D^2)^{1.17132}$	.062	.787	2.384	.98
Chestnut oak	24	$Y = 0.07852\ (D^2)^{1.20087}$	.049	892	2.555	.99
Dogwood	24	$Y = 0.09394\ (D^2)^{1.09946}$	.064	.848	3.780	.98
Hickory	24	$Y = 0.07998\ (D^2)^{1.18954}$	.071	.892	3.066	.98
		PIEDMONT				
Yellow-poplar	24	$Y = 0.07538\ (D^2)^{1.21347}$	.037	.880	3.904	.99
Sweetgum	24	$Y = 0.06448\ (D^2)^{1.19}$	.082	.888	2.988	.96
Red maple	23	$Y = 0.08232\ (D^2)^{1.20093}$	.065	.870	2.446	.98
White oak	23	$Y = 0.07168\ (D^2)^{1.16882}$	.100	.851	2.870	.95
Post oak	12	$Y = 0.07045\ (D^2)^{1.16035}$	.056	.904	1.217	.98
Southern red oak	25	$Y = 0.07947\ (D^2)^{1.15921}$	.072	.911	3.130	.97
Dogwood	24	$Y = 0.07366\ (D^2)^{1.22280}$	.060	.878	2.944	.98
Hickory	22	$Y = 0.07897\ (D^2)^{1.17591}$	.051	.849	3.027	.99
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 0.07851\ (D^2)^{1.19459}$	.050	.875	5.295	.99
Red maple	47	$Y = 0.08644\ (D^2)^{1.20142}$	.062	.865	5.595	.98
White oak	41	$Y = 0.07072\ (D^2)^{1.17881}$	.076	.823	5.295	.97
Dogwood	48	$Y = 0.08463\ (D^2)^{1.15352}$	.065	.863	6.734	.98
Hickory	46	$Y = 0.07934\ (D^2)^{1.18416}$	.062	.871	6.114	.98
Soft hardwoods	148	$Y = 0.07983\ (D^2)^{1.18817}$	.079	.892	18.763	.97
Hard hardwoods	196	$Y = 0.07703\ (D^2)^{1.17815}$	.067	.869	25.206	.98
All hardwoods	344	$Y = 0.07807\ (D^2)^{1.18353}$	.073	.879	44.016	.97

[a] In $\log_{10}$ form.

Table 12.—Regression equations and associated statistics for predicting the cubic volume of wood in the total tree for understory hardwoods based on diameter squared (D^2)

Species	Number trees sampled (N)	Regression equation	Standard error of estimate ($S_{y.x}$)[a]	Sample mean of x ($\bar{x}$)[a]	Corrected sums of squares for x ($\Sigma(x-\bar{x})^2$)[a]	Coefficient of determination (R^2)
		MOUNTAINS				
Yellow-poplar	24	$Y = 0.05748 (D^2)^{1.22852}$	0.058	0.869	3.226	0.98
Sourwood	11	$Y = 0.06472 (D^2)^{1.16537}$	.076	.961	1.222	.97
Blackgum	18	$Y = 0.06276 (D^2)^{1.15983}$	.071	1.002	1.553	.96
Red maple	24	$Y = 0.07256 (D^2)^{1.21748}$	.058	.860	3.148	.98
White oak	18	$Y = 0.04709 (D^2)^{1.23947}$	.057	.787	2.384	.98
Chestnut oak	24	$Y = 0.05116 (D^2)^{1.22801}$	.064	.892	2.555	.98
Dogwood	24	$Y = 0.07462 (D^2)^{1.10037}$	.075	.848	3.780	.97
Hickory	24	$Y = 0.05031 (D^2)^{1.22208}$	.089	.892	3.066	.96
		PIEDMONT				
Yellow-poplar	24	$Y = 0.05411 (D^2)^{1.24748}$	.042	.880	3.904	.00
Sweetgum	24	$Y = 0.04310 (D^2)^{1.19172}$	.112	.888	2.988	.94
Red maple	23	$Y = 0.06201 (D^2)^{1.24092}$	.072	.870	2.446	.97
White oak	23	$Y = 0.04451 (D^2)^{1.23922}$	.084	.851	2.870	.97
Post oak	12	$Y = 0.03549 (D^2)^{1.28517}$	.049	.904	1.217	.99
Southern red oak	25	$Y = 0.04596 (D^2)^{1.23763}$	.061	.911	3.130	.98
Dogwood	24	$Y = 0.05968 (D^2)^{1.19218}$	.051	.878	2.944	99
Hickory	22	$Y = 0.04670 (D^2)^{1.24274}$	.061	.849	3.027	98
		COMBINED EQUATIONS				
Yellow-poplar	48	$Y = 0.05569 (D^2)^{1.23870}$	.050	.875	5.295	.99
Red maple	47	$Y = 0.06750 (D^2)^{1.22670}$	.069	.865	5.595	.98
White oak	41	$Y = 0.04589 (D^2)^{1.23633}$	.073	.823	5.295	.97
Dogwood	48	$Y = 0.06773 (D^2)^{1.13963}$	.066	.863	6.734	.98
Hickory	46	$Y = 0.04838 (D^2)^{1.23349}$	.076	.871	6.114	.97
Soft hardwoods	148	$Y = 0.05847 (D^2)^{1.20940}$	.104	.892	18.763	.95
Hard hardwoods	196	$Y = 0.05140 (D^2)^{1.21046}$	.080	.869	25.206	.97
All hardwoods	344	$Y = 0.05405 (D^2)^{1.21249}$	.094	.879	44.016	.95

[a] In $\log_{10}$ form.

Table 13.—Predicted total-tree green weight of yellow-poplar trees[a] [b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	4	5	6	7	8	9				
2	13	17	21	24	28	31	35	38		
3	27	35	42	50	57	65	72	79	86	93
4	45	58	71	83	96	108	120	132	143	155
5		87	106	124	143	161	178	196	213	230
6			146	172	197	222	247	271	295	319

[a] Blocked-in area indicates range of data.
[b] Based on the equation $Y = 0.33899 (D^2Th)^{0.89180}$.

Table 14.—Predicted total-tree green weight of sourwood trees[a] [b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	4	5	6	8	9	10				
2	14	19	23	28	32	36	40			
3	31	40	49	59	68	77	85	94	103	
4	52	69	84	100	115	131	146	161	176	191
5		104	128	152	175	198	221	244	266	289
6			180	213	246	278	310	342	374	406

Blocked-in area indicates range of data.
Based on the equation $Y = 0.31997 (D^2Th)^{0.\ldots}$

Table 15.—Predicted total-tree green weight of blackgum trees[a] [b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	7	8	9	10	12				
2	16	21	25	29	33	37	41	45		
3	32	41	49	58	65	73	81	88	96	103
4	52	66	80	93	106	119	131	143	155	167
5		96	116	135	154	172	190	208	225	242
6			158	184	209	234	258	282	305	328

Blocked-in area indicates range of data.
[b] Based on the equation $Y = 0.52910(D^2Th)^{0.\ldots}$

Table 16.—Predicted total-tree green weight of sweetgum trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	4	5	6	7	8	9				
2	13	16	20	23	27	30	33	37		
3	26	33	41	48	55	61	68	75	81	88
4	43	55	67	79	91	102	113	124	135	146
5		82	100	117	135	151	168	184	200	216
6			138	162	186	209	232	254	277	299

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.34061(D^2Th)^{0.9\ldots}$

Table 17.—Predicted total-tree green weight of red maple trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	4	6	7	8	9	10	12			
2	15	20	24	28	33	37	41	45		
3	32	41	50	60	69	77	86	95	103	112
4	53	69	85	101	116	131	145	160	175	189
5		104	128	151	174	196	218	240	262	284
6			178	210	242	273	304	335	365	396

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.36353(D^2Th)^{0.91070}$.

Table 18.—Predicted total-tree green weight of white oak trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	6	7	9	10	11				
2	16	20	25	29	33	37	41			
3	32	41	49	58	66	74	82	90	98	105
4	52	67	81	95	108	122	135	147	160	173
5		98	119	140	159	179	198	217	235	253
6			163	191	218	245	271	297	322	347

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.46590(D^2Th)^{0.86130}$.

Table 19.—Predicted total-tree green weight of chestnut oak trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	6	7	9	10	11				
2	16	20	25	29	33	37	42	46		
3	32	42	50	59	68	76	84	92	100	108
4	53	69	83	98	112	126	139	153	166	179
5		101	123	144	165	186	206	226	245	264
6			169	199	227	255	283	310	337	364

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.44567(D^2Th)^{0.8324}$

Table 20.—Predicted total-tree green weight of post oak trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	6	7	8	10	11				
2	15	20	24	28	32	36	40			
3	31	40	48	56	64	72	80	87	95	
4	51	65	79	92	105	118	131	143	155	167
5		96	116	135	155	173	192	210	228	246
6			158	185	211	237	263	287	312	336

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.45540(D^2Th)^{0.8}$

Table 21.—Predicted total-tree green weight of southern red oak trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	7	8	10	11	12				
2	17	22	27	31	35	39	44	48		
3	34	44	53	61	70	78	86	94	102	
4	56	71	85	99	113	127	140	153	166	178
5		103	124	145	165	184	204	223	241	259
6			169	197	224	251	277	302	328	353

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.55167(D^2Th)^{0.8}$

Table 22.—Predicted total-tree green weight of dogwood trees[a] [b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	6	7	9	10	12	13				
2	19	25	31	36	41	47	52			
3	40	52	63	75	86	97	108	119	129	
4	67	87	107	126	144	163	181	199	217	235
5		130	159	188	216	244	271	298	325	351
6			221	261	300	338	376	414	451	488

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.48010(D^2Th)^{0.[illegible]}$

Table 23.—Predicted total-tree green weight of hickory trees[a] [b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	6	7	9	10	11				
2	16	20	25	29	33	37	41	46		
3	32	41	50	59	68	76	84	93	101	109
4	53	69	84	98	112	126	140	153	167	180
5		102	124	145	166	187	207	227	247	266
6			170	200	228	257	285	312	340	367

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.43736(D^2Th)^{0.87668}$

Table 24.—Predicted total-tree green weight of soft hardwood trees[a] [b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	4	5	6	7	9	10	11			
2	14	18	22	26	30	34	37	41		
3	29	37	46	54	62	70	78	85	93	100
4	48	63	77	90	104	117	130	143	156	168
5		94	114	135	155	174	194	213	232	251
6			159	187	215	242	269	296	322	348

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.35379(D^2Th)^{0.89267}$

Table 25.—Predicted total-tree green weight of hard hardwood trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	6	8	9	10	12				
2	17	22	26	31	35	39	44	48		
3	34	44	53	62	71	80	89	97	106	114
4	56	72	88	103	118	132	146	160	174	188
5		106	129	152	173	195	216	237	257	277
6			178	208	238	268	297	325	353	381

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.47221(D^2Th)^{0.87186}$.

Table 26.—Predicted total-tree green weight of all hardwood trees[a, b]

D.b.h. (inches)	Total-tree height (feet)									
	15	20	25	30	35	40	45	50	55	60
	Pounds									
1	5	6	7	9	10	11	12			
2	16	20	24	29	33	37	41	45		
3	32	41	50	59	67	75	83	92	100	107
4	53	68	83	97	111	125	138	152	165	178
5		100	122	143	164	184	204	224	244	263
6			168	197	226	254	281	309	336	362

[a]Blocked-in area indicates range of data.
[b]Based on the equation $Y = 0.43247(D^2Th)^{0.87655}$.

Table 27.—Predicted total-tree green weight of understory hardwoods based on d.b.h. alone[a]

Species	Total-tree green weight by d.b.h. class					
	1 inch	2 inch	3 inch	4 inch	5 inch	6 inch
	Pounds					
MOUNTAINS						
Yellow-poplar	4	21	56	111	189	294
Sourwood	5	26	67	134	227	350
Blackgum	5	25	64	125	210	320
Red maple	5	29	77	153	261	404
White oak	4	22	58	115	196	303
Chestnut oak	5	25	67	134	229	355
Dogwood	6	27	66	124	202	302
Hickory	4	24	64	127	219	340
PIEDMONT						
Yellow-poplar	5	24	63	126	214	332
Sweetgum	4	18	49	97	166	257
Red maple	5	26	69	137	233	359
White oak	4	22	58	114	193	296
Post oak	4	20	54	108	184	285
Southern red oak	5	25	65	128	217	335
Dogwood	5	27	71	142	244	380
Hickory	5	25	67	132	224	345
COMBINED PREDICTIONS						
Soft hardwoods	4	24	62	123	210	324
Hard hardwoods	5	25	64	127	214	328

[a]Predicted values in this table are based on equations in table 8.

Phillips, Douglas R.
1981. Predicted total-tree biomass of understory hardwoods. USDA For. Serv., Res. Pap. SE-223, 22 p. Southeast. For. Exp. Stn., Asheville, N.C.

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Linear Expansion Design Theory for Com-ply® Panels

COM-PLY® 21
REPORT

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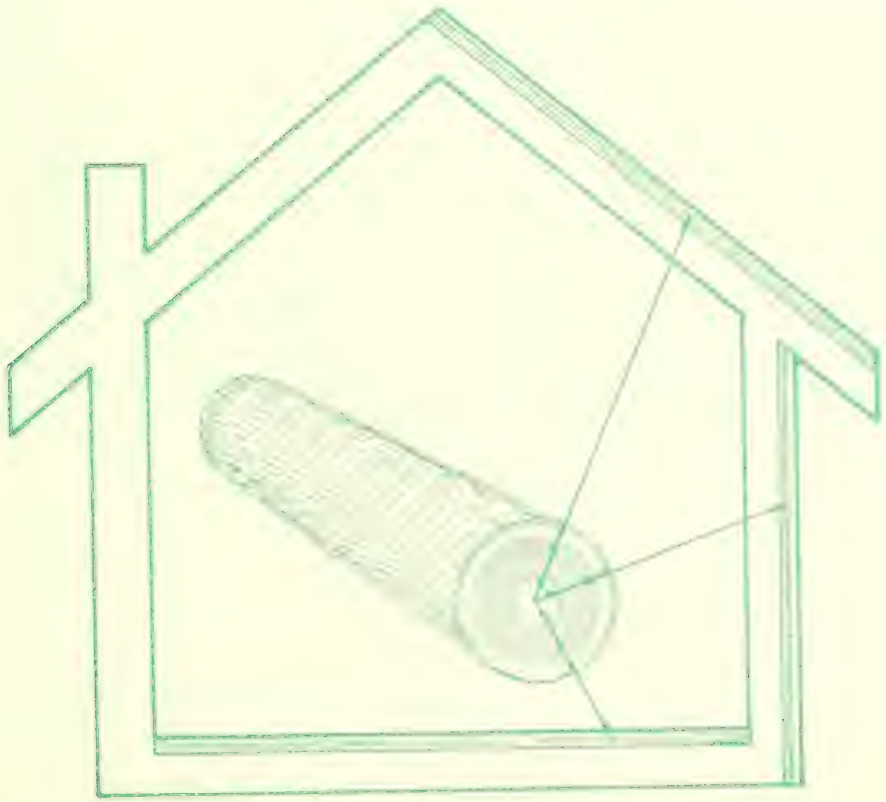

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Abstract.--A theory was developed for predicting linear expansion of COM-PLY panels with increasing panel moisture content. Equations are presented to predict panel expansion when the component materials behave elastically at low moisture contents and inelastically at high moisture contents. The strength and stiffness of a variety of veneer and particleboard components were measured to develop linear expansion equations. The results show it is possible to make COM-PLY panels with linear expansions that range from acceptable to totally unacceptable for residential construction.

KEYWORDS: Plywood, panel swelling, composite panels, dimensional stability.

COM-PLY® is a registered trademark of the American Plywood Association.

June 1981

LINEAR EXPANSION DESIGN THEORY FOR COM-PLY® PANELS

by

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Cooperative Research by

U. S. Department of Agriculture, Forest Service

Southeastern Forest Experiment Station

and

Washington State University

Wood Technology Section

College of Engineering

and

U. S. Department of Housing and Urban Development

Division of Energy, Building Technology

and Standards

PREFACE

This paper describes the first two phases of a four-phase cooperative research project between the Forest Service Wood Products Research Unit in Athens, Georgia, and the Wood Technology Section at Washington State University (WSU) in Pullman, Washington. The report develops theory for predicting the linear expansion of COM-PLY panels when their moisture content increases. Several manufacturers have started production of COM-PLY panels, but in some instances cross-panel expansion with increases in moisture content has been excessive. Research performed at WSU shows manufacturers how to predict linear expansion due to moisture changes in panels when strength and stiffness of materials are known.

The present report is one of a series on the possibilities of producing house framing and structural panels with flakeboard cores and veneer facings. These composite materials were designed to be used interchangeably with conventional plywood in homes. Research thus far has been limited to floor and roof panels but will be extended to include other types of COM-PLY panels.

In 1973, the home-building industry faced a shortage of lumber and plywood, and consequently rising prices. Both industry and government recognized that this situation was not temporary and that long-range plans for better using the Nation's available forest resources would be necessary to solve the problem.

The USDA Forest Service, the American Plywood Association, Washington State University, and the U. S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with flakeboard and veneer as a way of using not only more of the tree but also using less desirable trees and a greater variety of tree species than would conventional wood products. The flakeboard, which comprises a large portion of the COM-PLY panel, is made from milled wood that comes from forest residues, mill residues, or low-quality timber. Thus, use of such composites could greatly increase the amount of plywood available for residential construction, one of our major uses of wood, without eroding the Nation's timber supply.

Cooperative research on COM-PLY panels has also been performed by the American Plywood Association, which designed and tested COM-PLY panel products and incorporated them in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs, joists, and roof truss framing. Other reports will describe the overall project, report results of building demonstration houses, compare the strength of composite and solid-wood lumber, suggest performance standards for composite framing, and provide construction details on houses incorporating such materials. Still others will explore the economic feasibility of manufacturing composite lumber and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U. S. Department of Housing and Urban Development.

INTRODUCTION

Preliminary work by the American Plywood Association [1] has shown that COM-PLY® panels meeting requirements for mechanical properties can be made from a wide range of particle materials in the core layer. However, only one type of core material afforded lateral dimensional stability comparable to that of "matching" plywood when subjected to moisture change from 50% relative humidity equilibrium to equilibrium soak. This core material was composed of mechanically aligned flakes (strands) of softwood using a phenolic resin binder. The resulting COM-PLY® panel showed only 21% greater lateral dimensional change than that of "matching" plywood. These APA studies were considered encouraging and suggested strongly that orientation of the basic elements is the best approach to the problem of dimensional stability. In addition to lateral stability, the present study necessarily must address the equally important problem of longitudinal stability. This is a difficult problem because the matching material, plywood, is excellent in this regard and sets a high standard as the goal of the research.

It should be recognized that there may be some controversy regarding the interpretation of the APA results with aligned core materials in COM-PLY® panels. In any case, it was necessary to consider the effect of the alignment on the dimensional stability in the longitudinal direction of the panel; longitudinal stability may be adversely affected. Hence, compromises may be necessary.

If the compromises result in stability properties inferior to plywood, then a new approach will be necessary to define a "standard" or goal of the research. Rather than matching plywood, a new criterion can be established on the basis of the actual dimensional change that can be accommodated in the contemplated structures which are to embody the COM-PLY® material. To our knowledge, such a study has never been made.

In the long run, continued research of this type will provide the general ability both to predict the dimensional stability of the assembled panels from that of the veneers and core, and in turn to predict the dimensional stability of the core from the properties of the parent wood and from the core composition and consolidation parameters, such as particle geometry, degree of orientation, resin type and level, density, time and temperature in pressing. etc.

This project has four phases as listed below. Phases 1 and 2 are covered in the report. Phase 3 is presently underway with Phase 4 to be conducted subsequently.

Phase 1: Development and verification of a valid theory of dimensional stability applicable to such materials as particleboard, COM-PLY® and plywood.

Phase 2: Investigation of appropriate requirements for dimensional stability of structural panel materials under moisture changes.

Phase 3: Development of basic data on linear expansion, tensile, and compressive properties of various

types of material appropriate for cores of COM-PLY® panels.

Phase 4: Laboratory production and testing of experimental COM-PLY® panels based on information from Phases 1 through 3 to verify the theory of dimensional stability of COM-PLY® panels.

A brief background on each of these phases is provided in the following.

Phase 1
Development and Verification of a Theory of Dimensional Stability

The objective of this phase was to develop an adequate theory of linear expansion due to moisture change for plywood and for COM-PLY® panels. The theory must apply to expansion in both directions and to moisture changes anywhere within the hygroscopic range. Such a theory must recognize that the restraint of lateral swelling of veneers includes compressive strains far beyond the elastic range in lateral compression of wood, and thus that analysis on the basis of simple elastic theory is quite inadequate.

As an indication of the inadequacy of elastic analysis, Table 1 compares observed and predicted plywood swelling for four species from oven-dry to soaked. This is based on data from FPL 073 by Heebink *et al.* [13]. The predicted LE values in the column headed "Talbott" are based on the assumption that the lateral forces in the restrained veneers cannot exceed the lateral crushing strength of the wood at the existing moisture content. These values are seen to be in much better agreement with the observed values than are the predictions based on the assumption of elastic behavior (column headed "Heebink").

The complete theory will, of course, need to be more complex to cover the total hygroscopic range, including the lower MC levels where lateral elastic behavior does occur, and to cover other core materials such as random or aligned flakeboard.

To develop such a theory, the tangential compression behavior of wood needs to be determined to establish a family of stress-strain curves at various moisture levels, in addition to the properties measured by Heebink. Two species were used: loblolly pine (*Pinus taeda*) and Douglas-fir (*Pseudotsuga menziesii*). These are the two species most widely used in plywood and particleboard. They also represent two extremes in dimensional stability among softwoods. Cubes of wood of each species were loaded in tangential compression at various moisture levels from oven-dry to fiber saturation. Stress-strain curves were prepared, extending to strain values above 0.1 in./in. Tangential moduli of elasticity were computed from the slope of the stress-strain curves.

Using veneers matched to the wood cubes, tangential and longitudinal dimensional changes (unrestrained), and longitudinal moduli of elasticity were measured at the same moisture levels as above. The latter measurements, fortunately, can easily be made by means of the stress-wave equipment developed by WSU.

Plywood panels of each species were prepared from the tested veneers, and linear expansion in both directions was measured at the same moisture levels used in the measurement of tangential compression.

These results provide basic information on properties heretofore unavailable, and allow formulation of a more valid theory of dimensional stability of plywood, taking into account inelastic lateral restraint of veneers.

Phase 2
Investigation of Stability Requirements

Phase 2 attempted to determine appropriate requirements for linear stability, in both directions, of structural panel materials under moisture changes. Actual

Table 1. Comparison of Plywood Swelling Predictions

Linear Expansion (LE) from OD to soak for 50-50* plywood predicted by:

$$LE = FE_{\ell} \qquad \text{(simplistic)}$$

$$LE = \frac{FE_{\ell}\, E_{\ell} + FE_{t}\, E_{t}}{E_{\ell} + E_{t}} \qquad \text{(Heebink)}$$

$$LE = FE_{\ell} + \frac{2\sigma_{p\ell}}{E_{\ell}} \qquad \text{(Talbott)}$$

Species	$\sigma_{p\ell}$	E_t	E_ℓ	FE_t	Predicted LE of Plywood			
					FE_ℓ	Heebink	Talbott	Observed
	psi	10^6psi	10^6psi	in./in.	in./in.	in./in.	in./in.	in./in.
Aspen	180	0.011	1.25	0.0617	0.0030	0.0036	0.0033	0.0032
Y. Birch	430	0.036	1.63	0.0769	0.0049	0.0065	0.0054	0.0050
D. Fir	380	0.040	1.67	0.0504	0.0009	0.0021	0.0014	0.0015
Redwood	270	0.0085	0.415	0.0327	0.0018	0.0024	0.0031	0.0032

Where:

E_ℓ is the measured modulus of elasticity of wood in the longitudinal or grain direction (soaked condition) psi.

E_t is the measured modulus of elasticity of wood in the tangential direction (soaked condition) psi.

FE_ℓ is the measured unrestrained longitudinal movement of wood veneer from oven dry to soaked, in./in.

FE_t is the measured unrestrained lateral (usually tangential) movement of wood veneer from oven dry to soaked, in./in.

$\sigma_{p\ell}$ is the stress at proportional limit in lateral compression, green condition psi (Wood Handbook).

* Equal thicknesses of veneer in both directions.

linear expansion performance of panels now being successfully used structurally, was measured throughout the hygroscopic range. These included Douglas-fir and loblolly pine plywood, aspen waferboards, Australian and New Zealand particleboard panels, particleboard from the United Kingdom, particleboard from West Germany, and Plystran® composite panels. Through consultation with builders, building officials and code authorities, the means were determined which are currently being used to cope with moisture movement of panels; also, an effort was made to determine both the range of movement that these means can accommodate, and the range of moisture conditions which can be reasonably expected in practice.

These studies included materials used for sheathing, siding and flooring where nail or staple fastening is usual, as well as elastomeric-glued flooring and rigid-glued stressed-skin panel constructions. Both structural and esthetic effects were considered, including buckling of panel products and bowing of stressed-skin panels due to moisture in response to temperature gradients.

Phase 3
Data Base for Production of Experimental COM-PLY® Panels

In Phase 3, research will determine the effects of several composition and consolidation variables on the moisture responses of COM-PLY® core materials pertinent to the theory of Phase 1 and the standards produced in Phase 2. The variables include: species, resin level, density, particle geometry and orientation. The properties to be determined are linear expansion and stress-wave modulus of elasticity in both board directions, and thickness swell, all at five moisture conditions from oven-dry to soak. Bending strength and stiffness in both directions and internal bond strength will be measured at standard conditions (65% RH and 70°F). The Phase 3 work, although fairly routine, must be carried out with extreme care so as to be amenable to statistical analysis.

These results will provide a broad data base from which selections can be made to optimize the properties needed for the Phase 4 work.

Phase 4
Design and Testing of COM-PLY® Panels

Using the dimensional stability theory developed in Phase 1 and the data on panel materials from Phase 3, the best tentative compositions of COM-PLY® panels having properties suitable for sheathing, flooring, siding and stressed-skin structures will be selected to meet the requirements established in Phase 2. Such materials will be produced in the laboratory and fabricated into COM-PLY® panels, which will then be studied for stability in moisture change to verify the theory.

Detailed planning of Phase 4 must await results of earlier phases; however, it is anticipated that only one moisture level in addition to oven-dry and water soak would be needed in the testing phase, which would involve measuring linear expansion and EI product (or stiffness) in the grain and across-grain directions. Species combinations of face veneer and core material will be selected after consultation with other cooperators to insure the best combinations to meet technical requirements. Options of core density, particle geometry, degree of orientation, relative face and core thickness, and resin levels also must be considered in designing the Phase 4 boards.

PHASE I.
DEVELOPMENT AND VERIFICATION OF A THEORY OF DIMENSIONAL STABILITY

The Phase 1 work is reported in three main parts in chronological order. The first part consists of the measurement of properties of the two species of wood, the preparation of matching plywoods, and the measurement of the plywood properties as covered under "Determination of Basic Data." The mathematical development of the theory of linear expansion is covered in the second section under "Linear Expansion Models for a Layered Composite Gaining Moisture." The third section, which applies the theory to real plywoods and COM-PLY®, and to some hypothetical types of COM-PLY®, is headed "Examples of Applications of the Linear Expansion Theory." This is followed by a conclusions section.

DETERMINATION OF BASIC DATA

Laboratory Production of Plywood

Logs were procured from two sources: Douglas-fir (*Pseudotsuga menziesii*) from British Columbia, obtained by S. Chow of the Western Forest Products Laboratory in Vancouver; and loblolly pine (*Pinus taeda*) from Georgia, supplied by Gerald Koenigshof of the Southeastern Forest Experiment Station, Athens, Georgia.

Peeler blocks were shipped to the Western Forest Products Laboratory where they were peeled into veneer 1/8 in. thick. Veneer was clipped into sheets 24 in. wide and 51 in. long and then dried in a commercial dryer. Log ends were marked prior to peeling and veneer sheets were numbered sequentially so individual veneer sheets could be referenced accurately to their relative position within the logs. Discs matched to each end of the peeler blocks were also marked so that 1 in. cubes cut from the discs could be matched to selected veneer sheets. Physical properties of both cubes and veneers could therefore be compared. Matching was not one-to-one. Rather, the properties assigned to a given sheet of veneer were the average of several blocks within the same arc as the veneer and including the same annual rings.

Veneer was sorted so that sheets free from knots, holes, crossgrain or other characteristics affecting strength and stiffness could be obtained, and were cut to yield two 22 in. long, end-matched veneers. One of each pair was used to make plywood; the other was used to measure physical properties of veneers used to make plywood. Four 4-ply plywood panels 1/2 by 22 by 22 in. were made from the veneers using commercial plywood adhesives formulated for Douglas-fir and loblolly pine, respectively. Spread rates, assembly times and press schedules corresponded to practices recomended for the adhesives by their manufacturers. Four panels and veneers of each veneer type were evaluated.

Laboratory Testing Procedures

Reference sleeves were cemented in holes drilled 1 in. from each edge to give a 20 in. measuring span in each veneer and plywood specimen using an epoxy cement (Figure 1). These sleeves were used to measure linear expansion along and across the grain of veneers and plywood to the nearest 0.001 in. with a dial gauge fitted with conical pins to fit into the reference sleeves. Locations for thickness and stress-wave measurements are also shown in Figure 1.

The plywood panels, matching veneers and cubes were equilibrated for moisture content in a conditioning cabinet to the

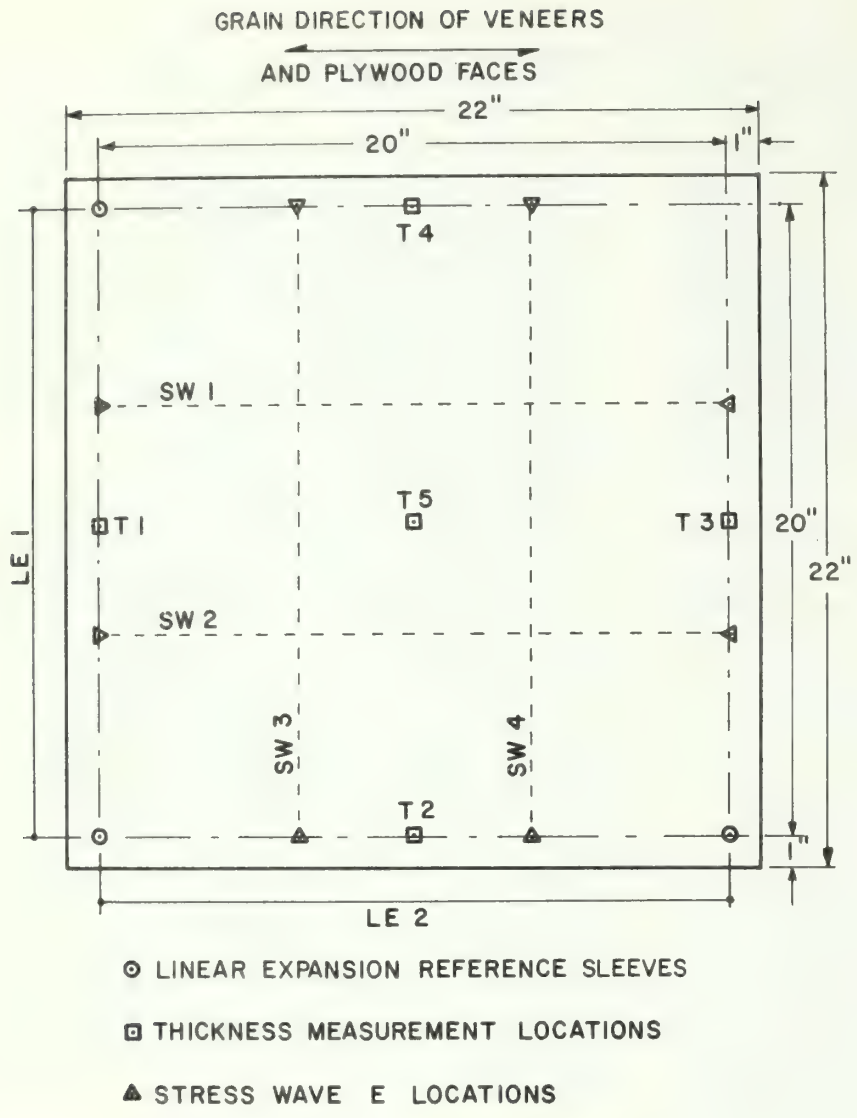


Figure 1. *Layout showing size and measurement locations for veneers and plywood specimens for Phase 1.*

temperature and relative humidity (RH) conditions listed in Table 2. The 90°F dry-bulb temperature was used to speed equilibration and reduce time necessary to gather data. Generally, at least two weeks were required to equilibrate samples to constant weight, with another week required to measure physical properties. The first materials measured in each case were the veneer sheets since these would equilibrate first due to their small thickness. All measurements on veneer and plywood were made in a room controlled at the Table 2 equilibration conditions so the moisture content of samples would not change during measurement.

Measurements made on the matching veneers were weight, linear dimension between reference sleeves parallel and perpendicular to the given direction, and stress-wave E parallel to the grain. The presence of lathe checks and lack of flatness of the individual veneers attenuate the stress-wave signal in the perpendicular-to-grain direction so that stress-wave E measurements in that direction are not reliable. For this reason, the tangential E was determined from the matching 1 in. cubes as described below.

The matching wood cubes to be tested at each humidity level were first weighed and then individually wrapped in thin PVC plastic film. Each specimen then was re-

Table 2. Equilibrium moisture content (%) of laboratory plywood panels, veneers and wood cubes.

	Relative Humidity @ 90°F(32°C) dry bulb					Vacuum-pressure soak 70°F(21°C)
	30%	57%	79%	87%	92%	
Sitka Spruce (Handbook)	5.9%	10.0%	15.1%	18.1%	21.3%	saturation
Douglas-fir						
veneers	4.3	8.6	13.9	17.3	18.8	134
cubes	6.76	10.7	15.4	18.6	20.0	137
plywood	7.2	10.9	15.8	19.4	21.1	85
Loblolly pine						
veneers	3.7	7.7	12.5	15.6	16.7	91
cubes	6.3	8.8	12.9	13.9	15.0	101
plywood	6.2	9.2	14.0	17.6	19.3	61
Inland Douglas-fir veneers						
air dried	6.8	10.7	15.9	18.3	19.2	130
commercial dryer 350°F(177°C) 14 min/pass						
one pass	4.7	8.5	13.3	16.1	17.1	122
two passes	4.3	8.0	13.0	15.5	16.3	122

moved from the conditioning room and quickly tested in tangential compression on a universal testing machine. The machine was operated at 0.02 in./minute crosshead speed with continuous recording of load and compression displacement. The loading was continued to a compression strain in excess of 0.1 in./in. to insure that the range covered would be greater than the maximum tangential free expansion of the wood from oven-dry to soak. After the test the cubes were oven-dried and reweighed to determine MC at the time of test.

Measurements made on the plywood panels at each humidity level were: weight, thickness at 5 locations, linear dimension between reference sleeves parallel and perpendicular to face grain, and stress-wave E at 2 locations in each direction.

After the measurements were completed for all humidity levels and the soaked condition, the plywood panels and veneers were oven-dried to constant weight and the weights recorded to afford a basis for MC calculations at all conditions. Some small error in MC estimation is introduced by the loss of extractives in the soak which preceded the oven-drying. It was considered that this was preferable to oven-drying the material before the equilibrations at the different humidities, since oven-drying significantly and permanently changes the hygroscopic properties of wood-based materials.

Results and Discussion

This section is devoted to presentation of the experimental results of Phase 1 pertaining to the characterization of the veneers from which the laboratory plywoods were made and discussion of some related considerations and concepts important to the development of a theory of linear expansion of plywoods and layered wood-based composites. The development of that theory in the next section, of course, constitutes the real "results" of Phase 1.

Equilibrium Moisture Content

Average equilibrium moisture content (EMC) of the matching veneers and wood cubes and of the laboratory-made plywoods of Douglas-fir and loblolly pine are shown in Table 2 for each of the selected RH's and for vacuum-pressure-soak. Corresponding values are also shown for inland Douglas-fir veneers which were either air-dried or dried in one or two passes through a commercial veneer dryer (14 minutes at about 350°F or 177°C).

It is immediately apparent that there are significant differences between the tabulated EMC values for the experimental materials, the *Wood Handbook* [30] values (Sitka spruce), and among the different experimental materials themselves.

The sources of these differences are several:

1. Different species have inherently different EMC curves—as also have materials of the same species from different geographical areas.
2. Drying at high temperature profoundly affects the hygroscopicity of wood-based materials—thus the differences in EMC between the laboratory veneers dried in a commercial veneer dryer and the matching cubes dried in the conditioning chamber at 90°F (32°C). The inland Douglas-fir veneers had EMC values about 2% lower when dried with one pass through the commercial dryer at 350°F (177°C) than when air-dried at room temperature. A second pass lowered the EMC values only about 0.5% further.
3. Plywood glues used in this experiment are much more hygroscopic than wood. A sub-experiment showed individual veneers coated with glue and then cured at press temperature had higher EMC values than similarly treated but unglued veneers.

4. Leaching of soluble materials from the samples during the soak before oven drying biases the oven-dry weight downward and the calculated MC's upward an undetermined amount. This would, of course, have a proportionately larger effect on the lower MC values. This leaching would also be expected to introduce a greater bias in the plywood and particleboard of Phase 2 because the glues and binders introduce more leachable substances.

The fact that the EMC of the plywood panels follows more closely that of the air-dried wood cubes than that of the matching veneers dried at high temperature is thus due to the opposing influences of the high-temperature drying and pressing which tends to reduce the hygroscopicity, and of the presence of the gluelines adding their higher hygroscopicity. The influence of the gluelines actually slightly overshadowed the effect of the high temperatures. However, the extra moisture would be expected to be confined to the gluelines where it would not affect the properties of the veneers themselves. Particleboards too have substantially reduced hygroscopicity due to the high temperatures to which the particles are often exposed in drying and to the higher press temperatures.

Thus, in attempting to predict the linear expansion characteristics of composite products such as COM-PLY®, it is more appropriate to base predictions on properties of the components evaluated at a given RH rather than at a given MC because cores and faces in general will arrive at different moisture levels when equilibrated at a given RH. (Further important considerations of effects of non-uniform moisture distributions encountered in actual field conditions will be discussed under Phase 2.)

Properties of Douglas-fir and Loblolly Pine At Six Moisture Conditions

Shown in Table 3 are average values of longitudinal and tangential MOE and tangential compressive strength for the Douglas-fir and loblolly pine experimental materials after equilibration at the five selected RH levels and after vacuum-pressure soak (VPS). The longitudinal MOE (E_l) was determined by the stress-wave technique on the matching veneers at each of the RH levels. The method is inappropriate for MC's above fiber saturation as the free water above the fiber saturation point is not coupled to the stress-wave but adds to the density and thus gives erroneously high E values. Stress-wave E is thus not shown for the VPS condition.

The tangential MOE (E_t) was determined from the maximum slope of the stress-strain curves of the tangential compression tests of the matching wood cubes. A typical curve for loblolly pine is shown as a solid line in Figure 2. The curving toe is caused by initial poor seating against the compression fixture due to roughness from swelling and has no significance to our problem. The sloping straight portion and its extrapolation back to zero load defines the elastic range, and its slope (σ/ϵ) is by definition E_t. The maximum ordinate of the curve is the tangential compression strength (σ_c'), and the approximately horizontal portion of the curve is the plastic range in which the stress is essentially constant. Consider too that in the range of plastic strain, where the curve is horizontal, the slope, and hence the effective E_t in that range, is zero. (This has important implications also to the restraint of swelling of panels by their fastening to framing and will be further considered in Phase 2.) For the purposes of the analysis used in development of the linear expansion theory, the tangential compression curves were simplified and idealized as shown in the dotted line in Figure 2.

Table 3. Properties of Douglas-fir and loblolly pine, and oriented-flake core board at six moisture conditions.

	Relative Humidity					Vacuum-pressure soak
	30%	57%	79%	87%	92%	
Douglas-fir						
E_ℓ stress-wave from veneers (10^6 psi)	2.821	2.968	2.597	2.453	2.494	
E_t from compression test of wood cubes	0.124	0.105	0.078	0.059	0.060	0.036
σ'_t from blocks (psi)	1852	1571	1291	1024	1017	617
Loblolly pine						
E_ℓ (10^6 psi)	2.149	2.085	1.985	1.912	1.882	
E_t (10^6 psi)	0.086	0.081	0.057	0.044	0.044	0.029
σ'_t (psi)	1881	1512	1128	879	895	562
Oriented-flake core board						
Unsanded E_ℓ (10^6 psi)	1.170	1.216	1.040	0.939	0.894	
E_t (10^6 psi)	0.175	0.183	0.148	0.130	0.120	
Sanded E_ℓ (10^6 psi)	0.985	1.011	0.886	0.753	0.700	0.626
E_t (10^6 psi)	0.257	0.277	0.230	0.185	0.171	0.167

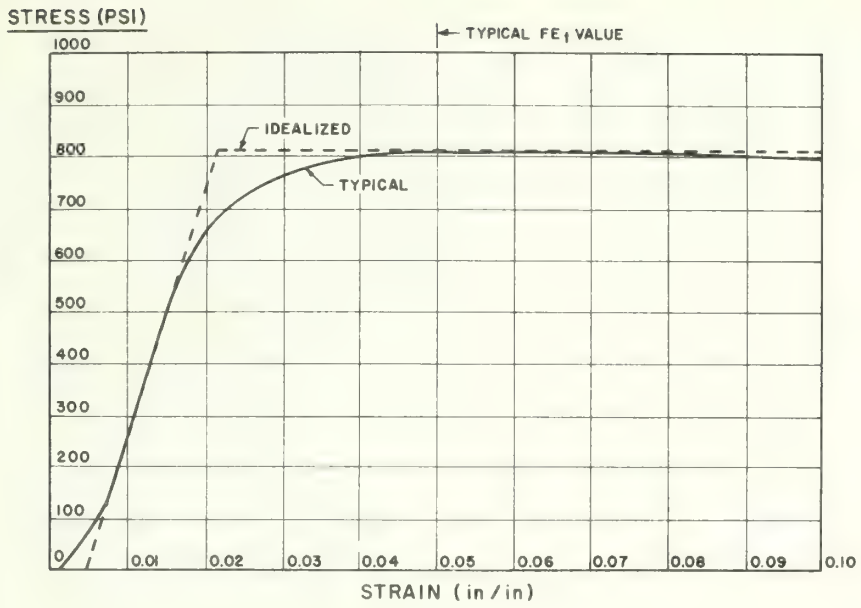


Figure 2. *Typical and idealized stress-strain curves for tangential compression of the matched wood cubes.*

The family of such idealized curves at the different moisture conditions is shown in Figure 3 for loblolly pine and in Figure 4 for Douglas-fir. Note that, while E_t and σ_t are steeply dependent on RH, the strain value at which the plastic range begins does not change much, and that the typical tangential free expansion, FE_t, at soak is much greater than the range of elastic strain. (The typical FE_t at soak is indicated at the top of Figure 2.)

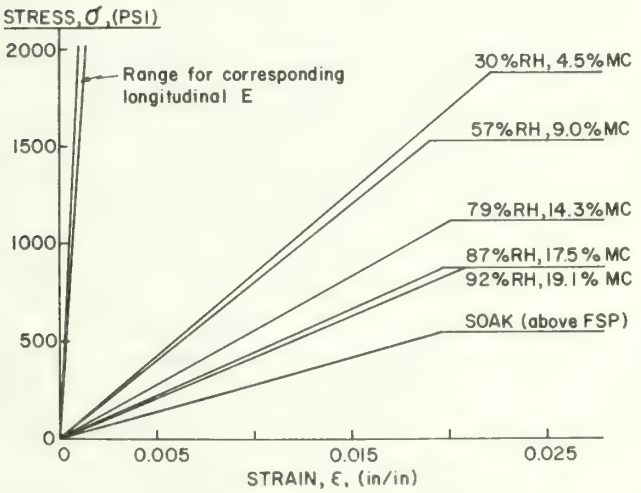


Figure 3. *Idealized stress-strain curves for loblolly pine in tangential compression.*

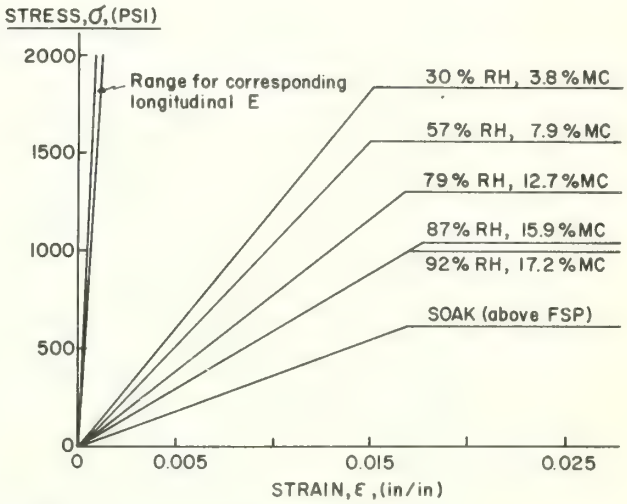


Figure 4. *Idealized stress-strain curves for Douglas-fir in tangential compression.*

The trends of E_t and σ_t' with MC are plotted in Figure 5 for loblolly pine and in Figure 6 for Douglas-fir. The trends of longitudinal stress-wave MOE, E_ℓ, are plotted against MC in Figure 7 for both loblolly pine and Douglas-fir. The E_ℓ is much less influenced by moisture conditions than is E_t. Going from 30% RH equilibrium to 92% only changes E_ℓ about 13% for Douglas-fir and about 11% for loblolly pine. The ratio of E_ℓ to E_t changes from about 25 to 1 at 30% RH to about 40 to 1 at 92% RH.

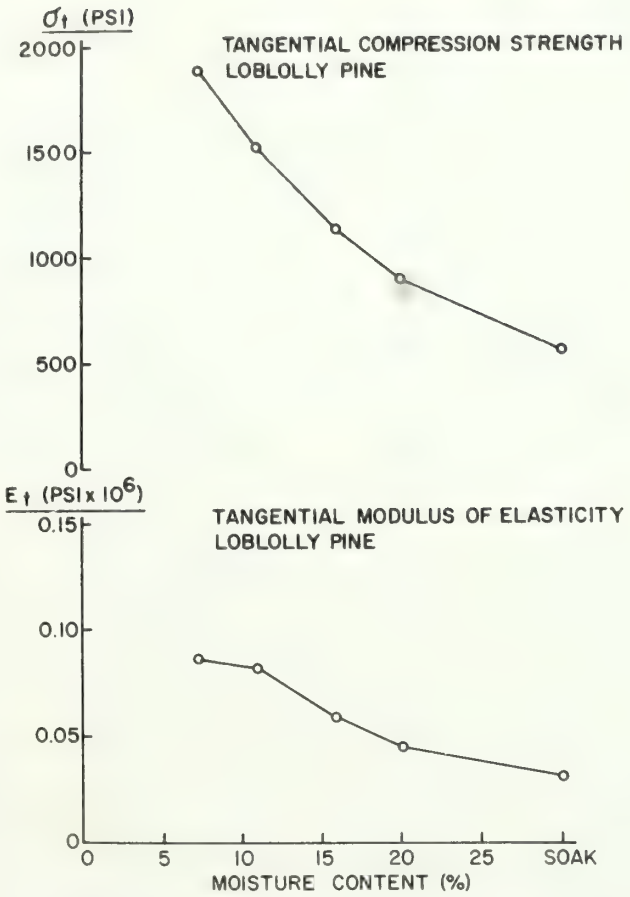


Figure 5. *Reduction in tangential strength and stiffness in loblolly pine with increasing moisture content.*

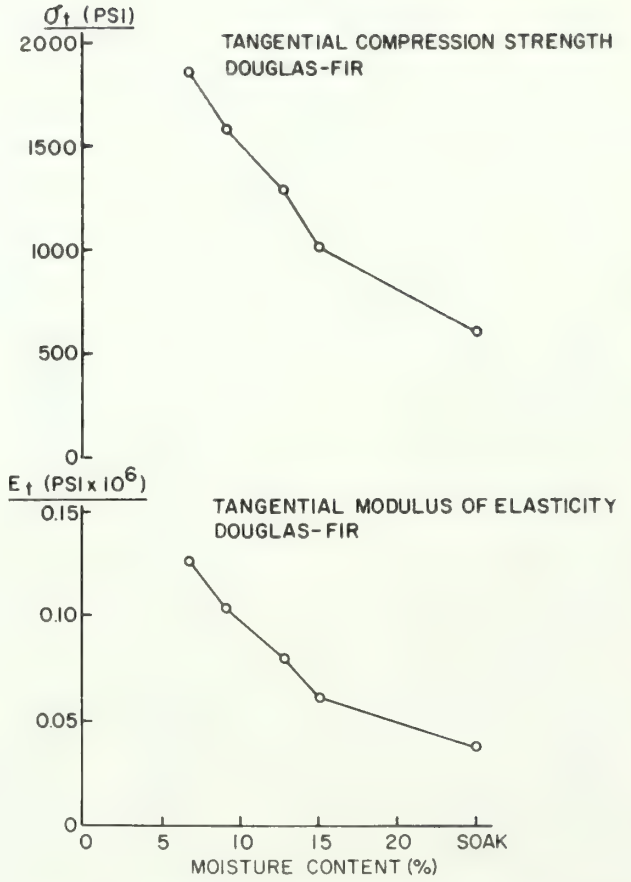


Figure 6. *Reduction in tangential strength and stiffness in Douglas-fir with increasing moisture content.*

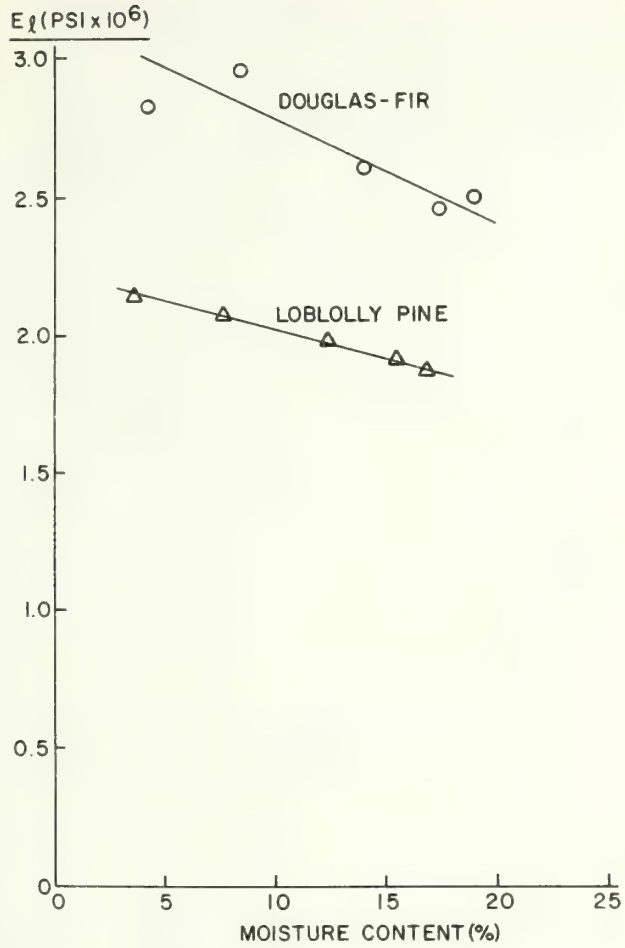


Figure 7. *Trends of longitudinal modulus of elasticity (stress-wave), E_l, with moisture content for Douglas-fir and loblolly pine veneers.*

Unrestrained Expansion of Veneers

Table 4 shows the average percent free expansion of the matching veneers of Douglas-fir and loblolly pine in the longitudinal (FE_ℓ) and tangential (FE_t) directions, and the percent moisture absorbed during the same humidity change.

The two species behave very similarly. The pine has slightly higher moisture absorption but no higher linear expansion. The tangential expansions are 25 to 60 times as great as the longitudinal. Note that restraint of the tangential free expansion from 30 to 57% would approach the limit of tangential elastic compressive strain—which from Figures 3 and 4 is seen to be about 0.017 in./in. or 1.7%. Restraint of the 30 to 79% FE_t would entail tangential compressive strains well into the plastic range in both species. It is this fact, primarily, which we believe causes plywoods to be substantially more stable in the upper moisture ranges than predicted by theories based on assumption of elastic action.

Summary

These, then, are the data and the considerations to be used in the next section, in which R. J. Hoyle, Jr. develops the mathematical expression of a theory of linear expansion of layered wood-based composites undergoing an initial increase in MC.

LINEAR EXPANSION MODELS FOR A LAYERED COMPOSITE GAINING MOISTURE

The simplest model for the linear expansion of a three-layer composite is one based on the assumption that the internal stresses all remain within the elastic range. This is not always a valid assumption, but it does provide a good starting point for developing a model. Figure 8 presents the basic notations which will be used in this discussion.

Consider a composite consisting of outer layers of equal thickness and properties, and an inner layer of a different thickness and different properties (Figure 9a). This could describe a piece of three-ply plywood. Consider the expansion in a direction parallel to the grain of the outer plies, and therefore across the grain of the inner ply. For rotary-cut veneer the inner ply expansion is, in this case, tangential to the annual rings.

When the MC of the composite is raised from some initial value to some higher final value, there is a tendency for each layer to expand, and if they were free to do so they would expand freely to the layer sizes in Figure 9b. If the coefficients of expansion due

Table 4. Unrestrained or free expansion of Douglas-fir and loblolly pine veneers from 30% RH equilibrium to equilibrium at 4 higher humidities and soak.

	57%	79%	87%	92%	Vacuum-pressure soak
Douglas-fir					
Longitudinal FE_ℓ (%)	0.04	0.05	0.6	0.07	0.10
Tangential FE_t (%)	1.25	2.69	3.50	3.78	4.91
Moisture absorbed (%)	3.9	8.4	11.9	12.4	83
Loblolly pine					
Longitudinal FE_ℓ (%)	0.05	0.06	0.05	0.06	0.08
Tangential FE_t (%)	1.21	2.60	3.44	3.81	6.23
Moisture absorbed (%)	4.3	9.3	12.5	14.0	125

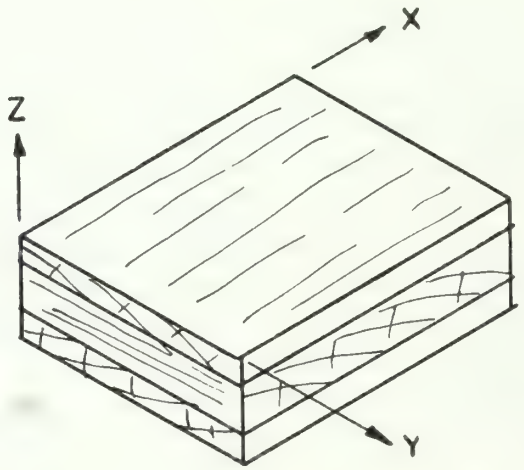


Figure 8. *Notation.*

LE Linear expansion of complete panel
E Modulus of elasticity (at higher moisture level)
σ Stress
σ' Compression strength (of higher moisture level)
ϵ Strain
FE Free (unrestrained) expansion of panel component
A Area
T Thickness

Subscripts

f face
c core
ℓ grain direction (or stronger direction)
t tangential direction (or weaker direction)
x direction parallel to face grain
y direction perpendicular to face grain

to moisture were known, these freely expanded lengths could be calculated.

Using the well-known method of superposition, we can consider the free expansion of the layers (Figure 9b), then apply a compressive force to the longest (or core) layer and an equal tensile force divided between the outer layers, large enough to make all layers the same length (Figure 9c). Under these conditions, if all layers were then bonded together, the gluelines would transmit the required stress to hold them in this position (Figure 9d).

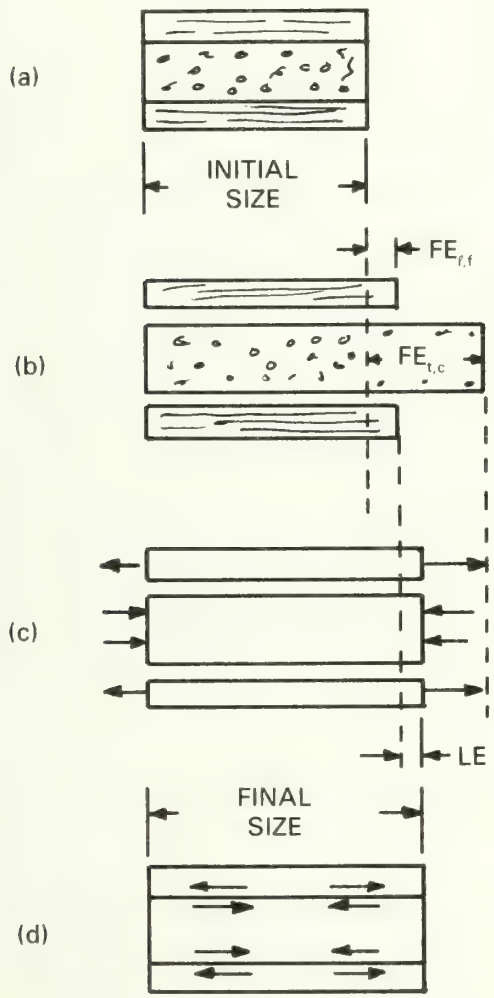
It will be convenient to assume the initial size is unity and the free linear expansions of the faces and core are $FE_{\ell,f}$ and $FE_{t,c}$. Using elastic theory, the strains due to applied stresses will be $\epsilon_f = \sigma_f/E_f$ and $\epsilon_c = \sigma_c/E_c$.

The expansion of the faces will be their free expansion plus their extension due to stress σ_f.

$$LE = FE_{\ell,f} + \frac{\sigma_f}{E_{\ell,f}}(1 + FE_{\ell,f}) \qquad (1)$$

The net expansion of the cores will be their free expansion minus their compression due to stress σ_c.

$$LE = FE_{t,c} - \frac{\sigma_c}{E_{t,c}}(1 + FE_{t,c}) \qquad (2)$$



E_f = Elastic modulus of the faces
E_c = Elastic modulus of the core
A_f = Total cross-sectional area of the two equal-size faces
A_c = Cross-sectional area of the core
σ_f = Stress on the face cross-section
σ_c = Stress on the core cross-section
$FE_{\ell,f}$ = Longitudinal free expansion of faces due to moisture
$FE_{t,c}$ = Free expansion of core due to moisture
LE = Total linear expansion of composite.

Figure 9a-d. *Method of superposition applied to linear expansion of plywood.*

Since $\sigma_c A_c = \sigma_f A_f$, for the forces on the face and core to balance,

$$\sigma_c = \frac{\sigma_f A_f}{A_c} \quad (3)$$

Also, with known relationships between longitudinal and tangential expansion,

$$\frac{FE_c}{FE_f} = \frac{S_t}{S_\ell} \quad (4)$$

where S_t and S_ℓ are the coefficients of expansion.

An expression for the compression stress can be obtained by equating Eqs. 1 and 2 and employing Eq. 3 such that

$$\sigma_c = \frac{FE_{t,c} - FE_{\ell,f}}{\frac{A_c(1 + FE_{\ell,f})}{A_f E_{\ell,f}} + \frac{(1 + FE_{t,c})}{E_{t,c}}} \quad (5)$$

and σ_f can be obtained From Eq. 3.

The linear expansion per unit of initial length will be:

$$LE_x = FE_{\ell,f} + \frac{\sigma_c A_c}{A_f E_{\ell,f}}(1 + FE_{\ell,f}) \quad (6)$$

or

$$LE_x = FE_{t,c} - \frac{\sigma_c}{E_{t,c}}(1 + FE_{t,c}) \quad (7)$$

Equations 6 or 2 would give identical values of linear expansion.

Assuming that all stresses are within the elastic range and that the core thickness is twice that of each face, we can use these equations to compute points on a linear expansion curve. For this we will use Phase 1 data on free expansion and elastic modulus of Douglas-fir at different moisture levels as shown in Tables 5 and 6.

The longitudinal linear expansions based on an assumption that the layers behave elastically and do not creep were calculated using Eqs. 5 and 6. In order to have points more uniformly distributed over the range from 3.8 to the fiber saturation point (FSP), these calculations were also made by interpolation of elastic properties and free expansion measurements between the experimental moisture levels. These results appear as Table 7; the linear expansions are also plotted in Figure 10 for comparison to other prediction models now to be developed.

These equations (5 and 6) can be simplified if one is willing to consider that $1 + FE_{\ell,f}$ and $1 + FE_{t,c}$ are not materially different from 1.0. In that case:

$$\sigma_c = \frac{(FE_{t,c} - FE_{\ell,f})\, E_{\ell,f}\, E_{t,c}}{(A_c/A_f\, E_{t,c} + E_{\ell,f})} \quad (8)$$

$$LE_x = FE_{\ell,f} + \frac{\sigma_c A_c}{E_{\ell,f} A_f} \quad (9)$$

When $A_c/A_f = 1$ (area of center = sum of areas of faces)

$$LE_x = FE_{\ell,f} + \frac{(FE_{t,c} - FE_{\ell,f})\, E_{t,c}}{E_{t,c} + E_{\ell,f}} \quad (10)$$

The assumption that all stresses are within the elastic range is usually not valid, as will presently be explained. In this example, the computed values of stress (σ_c) are usually above the proportional limit stress for unseasoned Douglas-fir in the tangential direction, so the conditions are generally in the elastoplastic range. This simply means that the maximum stress that can be exerted by the expansion of a layer in the tangential direction is its plastic stress. Continued expansion beyond the elastic strain at the proportional limit stress proceeds at this constant level of stress.

Linear Expansion When Stress Exceeds Elastic Limit

Two features of stress-strain behavior should be considered in modeling linear expansion. They are the strain characteristics when stress exceeds the elastic limit, and creep. The two phenomena are not clearly separate but will be considered separately.

Table 5. Expansion of Douglas-fir veneers

Change in MC (%)	Free Tangential (FE_t) Expansion (in./in.)	Free Longitudinal (FE_l) Expansion (in./in.)
3.8 to 7.9	0.01225	0.00040
3.8 to 12.3	0.02626	0.00057
3.8 to 15.9	0.03456	0.00064
3.8 to 17.1	0.03768	0.00070
3.8 to FSP (soak)	0.04748	0.00112

Table 6. Elastic modulus of Douglas-fir

MC (%)	MOE, Tangential (psi)	MOE, Longitudinal (psi)
3.8	123,000	2,833,000
7.9	105,000	2,631,000
12.3	79,000	2,416,000
15.9	59,000	2,332,000
17.1	60,000	2,316,000
FSP	37,000	2,120,000

Table 7. Calculation of internal stress and linear expansion for direction parallel to face grain of 3-ply Douglas-fir, by elastic theory.

MC (%)	$E_{t,c}$ (10^6psi)	$E_{,f}$ (10^6psi)	$FE_{t,c}$ (in./in.)	$FE_{,f}$ (in./in.)	c (psi)	LE_x (in./in.)
3.8	0.123	2.833	0.0	0.0	0	0.0
7.0	0.109	2.675	0.0096	0.0003	964	0.0007
7.9	0.105	2.631	0.0122	0.0004	1383	0.0008
10.0	0.093	2.530	0.0189	0.0005	1620	0.0011
12.3	0.079	2.416	0.2626	0.0006	1691	0.0013
15.0	0.068	2.360	0.3246	0.0006	2041	0.0015
15.9	0.059	2.332	0.0346	0.0006	1889	0.0014
17.1	0.060	2.316	0.0377	0.0007	2087	0.0016
20.0	0.048	2.220	0.0413	0.0008	1872	0.0017
25.0	0.037	2.120	0.0475	0.0011	1657	0.0019

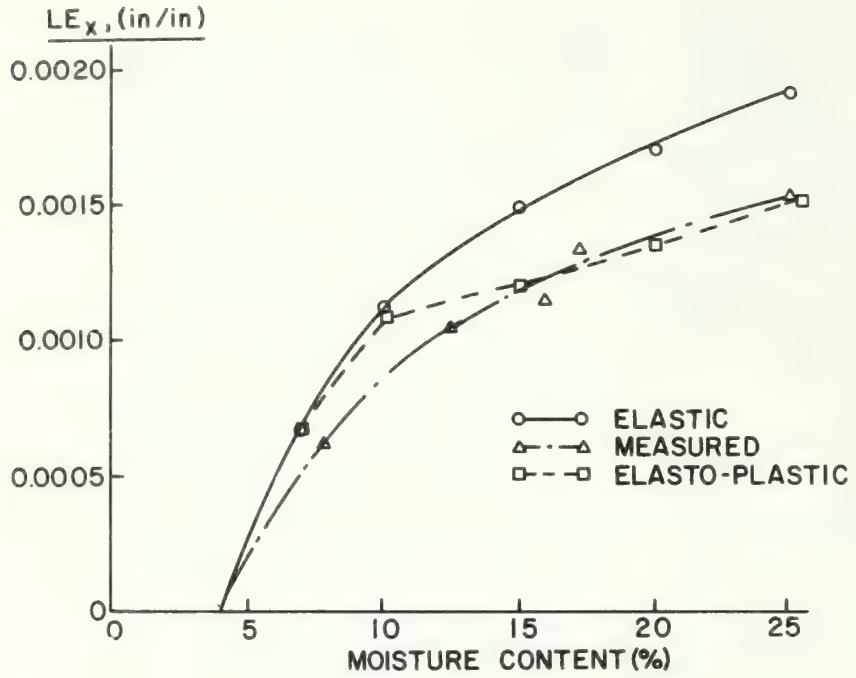


Figure 10. *Linear expansion for several models compared to measured results parallel to face grain of 3-ply Douglas-fir veneer composite.*

The elastic limit *in tension* is at about 60% of ultimate. At stresses above this level the strain increases more rapidly than the stress. The previous elastic-theory treatment of linear expansion indicates that tension stress will probably remain well below the elastic limit in the *parallel-to-grain* direction.

The elastic limit in compression *perpendicular to grain* is more well-defined, and when this strain is exceeded the stress does not increase further. Experimental results on Douglas-fir obtained in this research provide the idealized elastoplastic stress-strain curves shown in Figure 11. The maximum stress in compression was measured, and the curves obtained on an X-Y plotter were much like those in Figure 11.

In the Figure 9 situation, the stress in the core layer cannot actually exceed the plastic stress, σ_c', represented by the horizontal portions of the curve in Figure 11. Under these conditions, Eq. 6 takes the form

$$LE_x = FE_{\ell,f} + \frac{\sigma_c' A_c}{E_{\ell,f} A_f}(1 + FE_{\ell,f}) \qquad (11)$$

whenever σ_c computed by Eq. 5 equals or exceeds σ_c' from Figure 11 for the appropriate MC.

To permit computation of the linear expansion at discrete increments of MC, the experimentally measured values of elastic modulus of Douglas-fir faces (longitudinal, in our example) and cores (tangential, in our example) have been plotted in Figures 12a and 12b.

Also, since $FE_{\ell,f}$ is an extremely small part of $(1 + FE_{\ell,f})$ in Eq. 10, the second term can be simplified to make the equation:

$$LE_x = FE_{\ell,f} + \frac{\sigma_c' A_c}{E_{\ell,f} A_f} \qquad (12)$$

For convenience, the free expansions of the faces and cores are plotted in Figure 13. To obtain linear expansion from the 3.8% MC base, first calculate σ_c from elastic theory and see if it is above or below the plastic stress level as interpolated from Figure 11 for the corresponding MC. Results of such calculations using Eqs. 5 and 6 are tabulated in Table 8 ($A_c/A_f = 1$). These show that the internal stress by elastic theory begins to exceed the plastic stress at some MC between 7 and 10%.

Linear expansion is calculated using Eq. 8 when internal stress is below the plastic

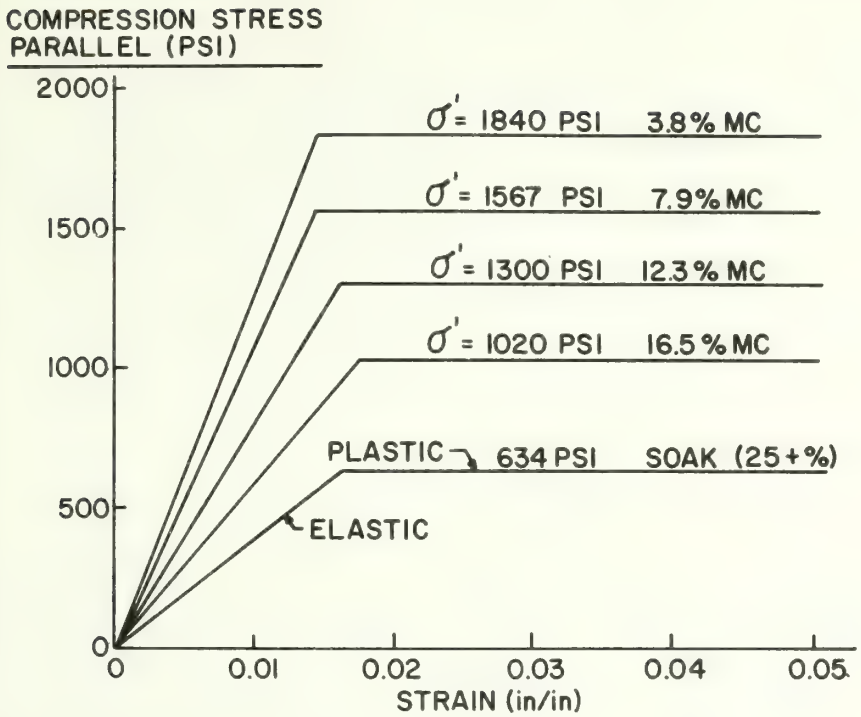


Figure 11. *Douglas-fir strain (in./in.).*

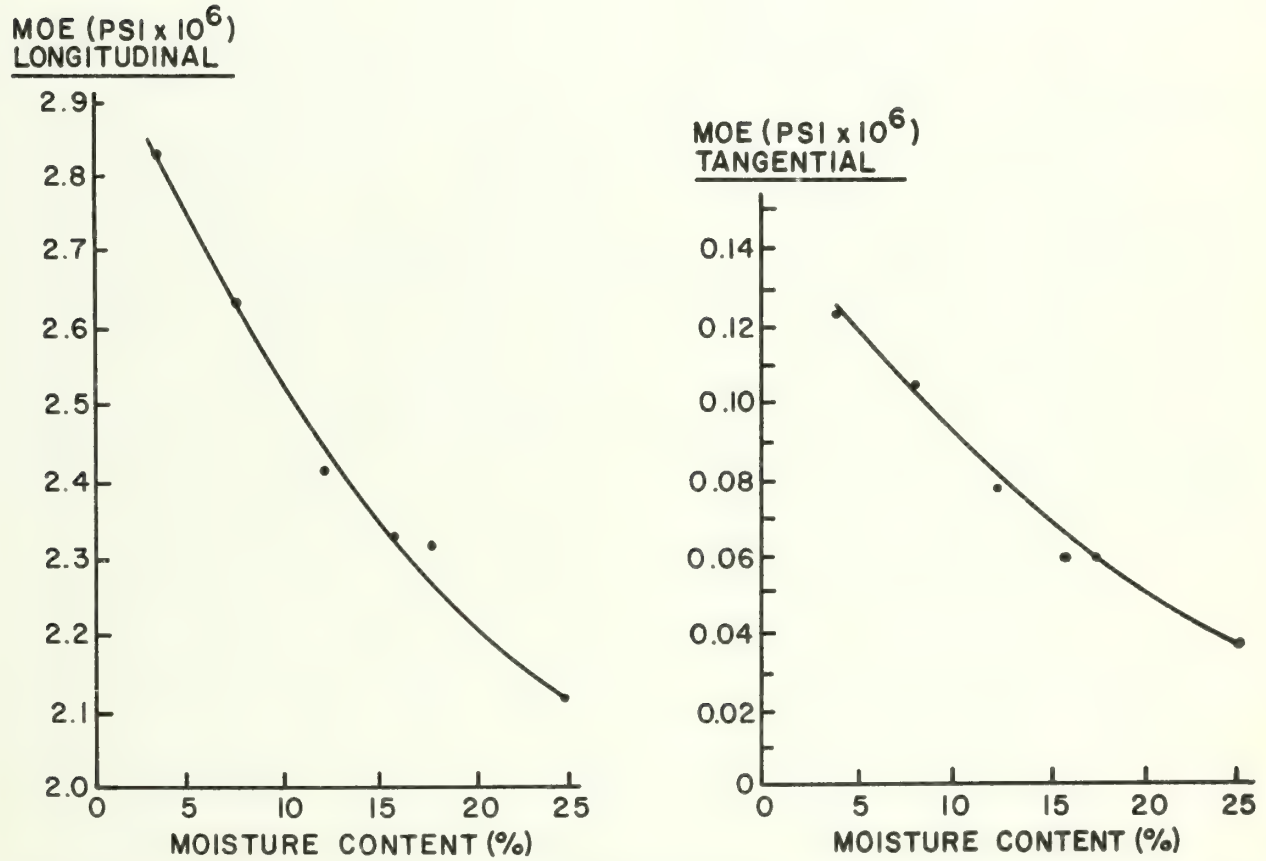


Figure 12a and b. *Change in modulus of elasticity in the longitudinal direction (a) and in the tangential direction (b) of Douglas-fir as a function of moisture content.*

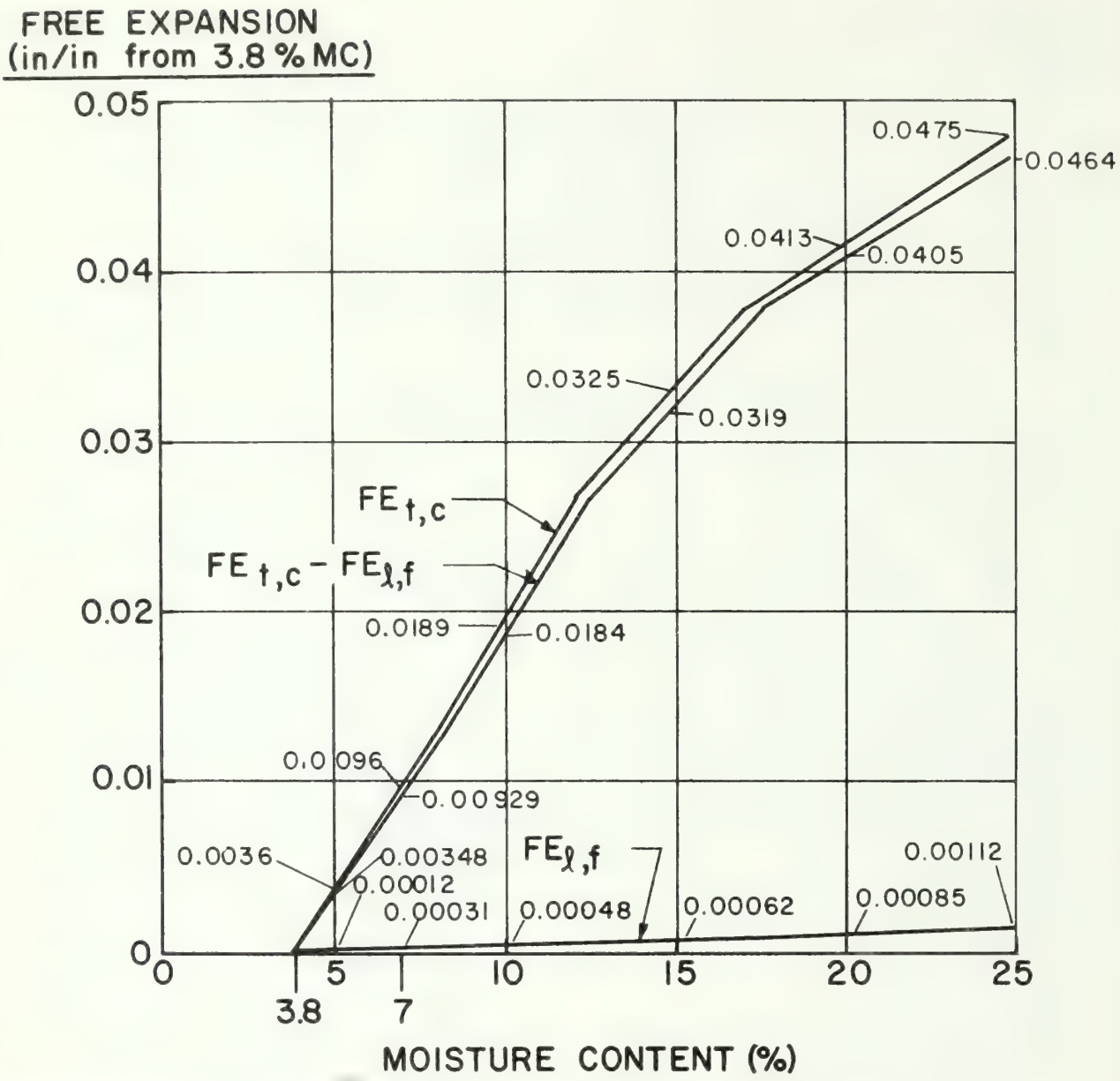


Figure 13. *Free expansion of face and core measured parallel to face grain of composite.*

Table 8. Calculation of internal stress for direction parallel to the face grain, Douglas-fir, elastic theory.

MC	$E_{t,c}$	$E_{\ell,f}$	$FE_{t,c}$	$FE_{\ell,f}$	σ_c	σ'_c
(%)	(10 psi)	(10 psi)	(in./in.)	(in./in.)	(psi)	(psi)
3.8	0.123	2.833	0.0	0.0	0	1840
7.0	0.109	2.675	0.0096	0.0003	964	1627
10.0	0.093	2.530	0.0188	0.0005	1620	1440
15.0	0.068	2.360	0.0325	0.0006	2040	1184
20.0	0.048	2.220	0.0413	0.0008	1872	861
25.0	0.037	2.120	0.0475	0.0011	1657	634

Table 9. Linear expansion by the elasto-plastic theory for direction parallel to the face grain, Douglas-fir.

MC Change	$FE_{\ell,f}$	$\frac{\sigma_c}{E_{\ell,f}}$	$\frac{\sigma'_c}{E_{\ell,f}}$	LE_x
%	in./in.	in./in.	in./in.	in.
3.8 to 7	0.0003	0.00036	--	0.0007
3.8 to 10	0.0005	--	0.00061	0.0011
3.8 to 15	0.0006	--	0.00057	0.0012
3.8 to 20	0.0009	--	0.00050	0.0014
3.8 to 25	0.0011	--	0.00039	0.0015

stress and Eq. 11 when it exceeds the plastic stress. Results are presented in Table 9, and plotted in Figure 10.

Consideration of the Effect of Creep

It is seen that the predictions of linear expansion by the elastoplastic theory, while being substantially in better agreement with measured values than are the predictions of the elastic theory, tend also to overestimate linear expansion, especially in the lower moisture ranges. It was felt that this remaining discrepancy was probably due to the effects of creep, or relaxation, on the internal stresses in the expanding composite. A theoretical analysis of the effects of creep on the linear expansion of composites was therefore undertaken by Hoyle.

Introduction of the effects of creep into the model requires certain information about creep under stress in wood. The experimental work of Phase 1 was not set up to obtain such information, which is available only in general terms from the wood technology literature and relating mainly to longitudinal stresses. Based on the meager information available, Hoyle's analysis of the effect of creep assumed that creep is proportional to stress, and that the constant of proportionality is the same for longitudinal tensile stress within the elastic range and for tangential compression stress both in the elastic range and in the plastic range.

The analysis, based on these assumptions, would lead to the following conclusions on the effects of creep:

1. Throughout the moisture range, creep should significantly reduce the internal stresses within the composite.
2. In the lower moisture ranges where all stresses are in the elastic range, creep would have no effect on linear expansion.
3. In higher moisture ranges, the stress reduction due to creep would mean that the tangential compression stresses would not enter the plastic range until higher moisture levels were reached, which in turn leads to slightly higher predicted linear expansions.

Thus the introduction of creep would result in predicted linear expansions further from the measured values rather than closer to them. For this reason, the rather lengthy creep analysis is not presented in this report but is reserved pending development of pertinent data on creep in wood stressed in tangential compression.

EXAMPLES OF APPLICATIONS OF THE LINEAR EXPANSION THEORY

Because of the demonstrated widely varying degrees of hygroscopicity of the components of COM-PLY® panels, it seems appropriate to make stability predictions based on equilibrium at specified levels of relative humidity as used in the Phase 1 experiment, rather than at specified levels of MC which, in general, are not achievable throughout a given board.

Thus we will now apply the theory developed above to predict linear expansion from 30% RH in both directions in both the Douglas-fir and loblolly pine laboratory plywoods at the RH levels and soak condition used in the Phase 1 experiment. This will be followed by linear expansion predictions for a Douglas-fir-face, aligned-core COM-PLY® for which we have some data from Phase 2, and for some hypothetical types of COM-PLY®.

Consider first the plywoods. These were of 1/2 in., 4-ply construction using 1/8 in. veneers. Thus the total face thickness and core thickness are equal ($A_f/A_c = 1$). This means the predicted expansions in both directions will be the same, so we will compare the predicted expansions by both the elastic and elastoplastic methods to the measured values averaged for the two directions. Equality of the face and core thicknesses also allows use of the more simplified equations.

Loblolly Pine Plywood

The pertinent properties—longitudinal and tangential MOE, longitudinal and tangential free expansion from 30% RH, and tangential compressive strength—are recapitulated in the first section of Table 10 for the five moisture conditions used in the experiment. The longitudinal E value for the soaked condition is missing because the stress-wave method of measurement is not applicable to soaked veneers. The value for 92% RH was substituted. The calculated elastic stress values (Eq. 8) are shown in the next line. These are compared to the measured tangential compressive strength values for each moisture condition; the smaller value is underlined. This comparison is the criterion of choice between the elastic-action equation (Eq. 10) and the plastic-action equation (Eq. 12). If the tangential compressive strength is smaller than the calculated elastic stress, the lateral restraint of the veneers must be in the plastic range and the plastic-action equation is used. Thus it is seen that only in the 30 to 57% RH increment can the action be assumed to be elastic.

The predicted LE values (applicable to both directions) and the measured LE values averaged for both directions are shown in the last section of Table 10 and and plotted in Figure 14 for visual comparison.

Of course, both the elastic and elastoplastic predictions coincide for the 57% RH equilibrium because the calculated lateral stress in the veneers is less than the measured tangential strength. At higher humidities the two predictions diverge increasingly until soak, where the elastoplastic prediction is only about two-thirds of the elastic prediction. The measured average expansion is about a third lower than the prediction at 57% RH, but approaches much nearer the elastoplastic prediction at higher humidities. Notice that both predictions and the average measured values *decrease* with increasing humidity between the 79 and 87% RH levels. Because this plywood is made from very straight-grained and nearly clear veneers, it is very stable, with only 0.14% expansion from 30% RH to soak. Plywoods from C and D veneers with many knots and with much cross-grain and steep grain can have expansions three times as great in the same range of moisture conditions (see Phase 2 results). Such veneer characteristics have a dual effect in increasing linear expansion: the grain

Table 10. Summary table for loblolly pine showing measured wood properties at five moisture conditions, of matching veneers and wood cubes; also shown are predicted and measured linear expansions, from 30% RH, of four-ply plywood having equal core thickness and total face thickness. Predicted linear expansions for such plywood are the same for both x and y directions (parallel and perpendicular to the face grain respectively), and the measured linear expansions are thus averaged for x and y directions for comparison.

		Moisture Conditions				
	RH%	1	2	3	4	5
		57	79	87	92	(VP soak)
	Plywood Moisture Content %	9.2	14.0	17.6	19.3	61
Longitudinal MOE (veneer, stress-wave)	E_ℓ 10^6psi	2.08	1.98	1.91	1.88	(1.88)
Tangential MOE (wood cubes, comp.)	E_t 10^6psi	0.081	0.059	0.044	0.044	0.029
Longitudinal Free Expansion from 30% RH	FE_ℓ in./in.	0.0005	0.0006	0.0005	0.0006	0.0008
Tangential Free Expansion from 30% RH	FE_t in./in.	0.0121	0.0260	0.0344	0.0381	0.0623
Maximum tangential compressive strength	σ'_t psi	1512	1128	879	895	562
calculated stress elastic	σ_t psi	894	1373	1458	1612	1756
Predicted LE, elastic	$\hat{LE}$ %	0.093	0.131	0.126	0.146	0.173
Predicted LE, elasto-plastic	$\hat{LE}$ %	0.093	0.117	0.096	0.108	0.110
Measured LE, averaged for x & y directions	$\overline{LE}$ %	0.065	0.096	0.081	0.090	0.138

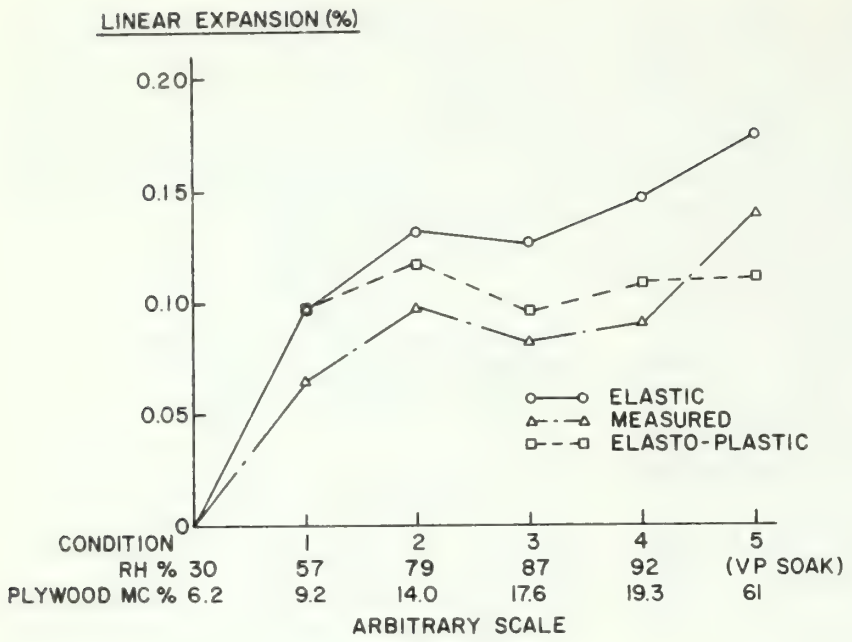


Figure 14. *Linear expansion from 30% RH of 4-ply loblolly pine plywood at five conditions of increasing moisture: a comparison of measured values with values predicted by assuming either elastic or elastoplastic action of the components. The measured values are averaged for the x and y directions.*

deviations result in higher longitudinal free expansion, thus increasing the first term of the prediction; and the lower longitudinal stiffness, due to the deviations, increases the second term, in which the stiffness occurs in the denominator.

Douglas-fir Plywoods

Returning now to the Douglas-fir laboratory plywoods, let us consider them on the same basis as the pine above: we will compare measured expansions from 30% RH, averaged for both directions, with predicted expansions—all at the four humidity levels and the soak conditions of the experiment. The required material properties and the calculated and actual expansions are tabulated in the same format as with the pine, Table 11, and plotted in Figure 15.

Again, comparison of calculated elastic tangential stress with measured tangential compressive strength indicates that the tangential compression will be in the plastic range at moisture conditions above the 57% RH level (see underlined values, Table 11). Beyond this point the elastic and elastoplastic predictions diverge, and the latter closely follows the average measured expansions. Again, this is a very stable plywood having nearly clear straight-grained veneers.

Application of the Linear Expansion Theory to COM-PLY

Prediction of linear expansion of COM-PLY® panel materials would nominally require knowledge of the lateral compression strength of the core materials, as well as of the face veneers, as a function of moisture level. Samples of a commercial COM-PLY® and of its aligned flakeboard core were included in the five-level moisture equilibration experiment, but no provision was made to measure the lateral compression strength of the core as a function of moisture level. We therefore performed a small side experiment in which 1 in. cubes laminated from the COM-PLY® core material were tested in compression in the two panel directions in soaked condition to give the ultimate strength values σ_ℓ' and σ_t' at soak. These were found to be, as expected, substantially higher in both directions than the calculated corresponding elastic stresses required for

Table 11. Summary table for Douglas-fir, showing measured wood properties at five moisture conditions of matching veneers and wood cubes; also shown are predicted and measured linear expansions, from 30% RH, of four-ply plywood having equal core thickness and total face thickness. Predicted linear expansions for such plywood are the same for both x and y directions (parallel and perpendicular to the face grain respectively), and the measured linear expansions are thus averaged for x and y directions for comparison.

		Moisture Conditions				
		1	2	3	4	5
	RH%	57	79	87	92	(VP soak)
Plywood Moisture Content %		10.9	15.8	19.4	21.1	85
Longitudinal MOE (veneer, stress-wave)	E_ℓ 10^6psi	2.97	2.60	2.45	2.49	(2.49)
Tangential MOE (wood cubes, comp.)	E_t 10^6psi	0.105	0.078	0.059	0.060	0.036
Longitudinal Free Expansion from 30% RH	FE_ℓ in./in.	0.0004	0.0005	0.0006	0.0007	0.0010
Tangential Free Expansion from 30% RH	FE_t in./in.	0.125	0.0269	0.0350	0.0378	0.0491
Maximum tangential compressive strength	σ'_t psi	1571	1291	1024	1017	617
calculated stress elastic	σ_t psi	1227	1999	1982	2173	1703
Predicted LE, elastic	$\hat{LE}$ %	0.084	0.126	0.144	0.157	0.169
Predicted LE, elasto-plastic	$\hat{LE}$ %	0.084	0.100	0.102	0.111	0.125
Measured LE, averaged for x & y directions	$\overline{LE}$ %	0.056	0.090	0.085	0.097	0.123

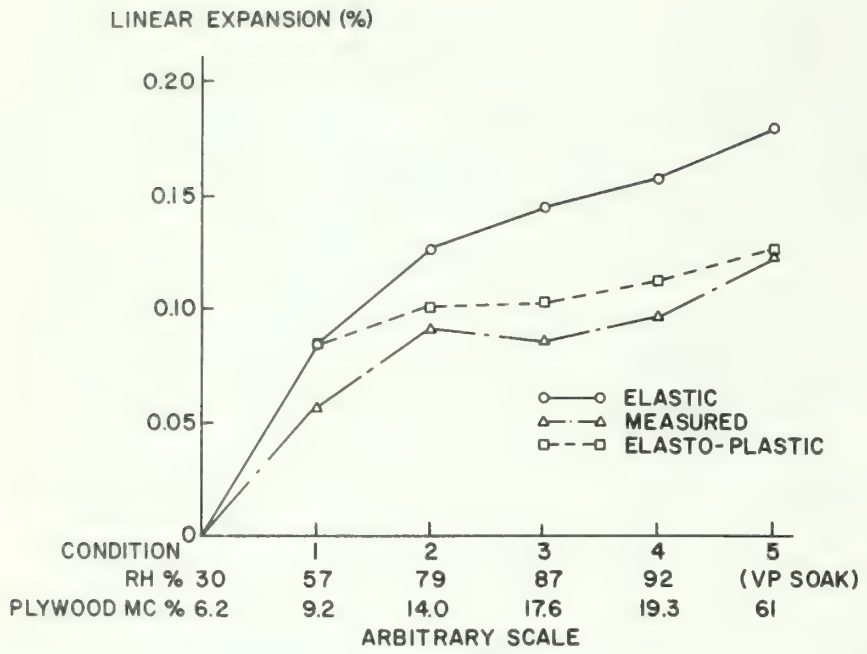


Figure 15. *Linear expansion from 30% RH of 4-ply Douglas-fir plywood at five conditions of increasing moisture: a comparison of measured values with values predicted by assuming either elastic or elastoplastic action of the components. The measured values are averaged for the x and y directions.*

full elastic restraint of the measured free expansions at soak. This strongly implies that flakeboard COM-PLY® cores, either aligned or random, will behave elastically in the composite throughout the moisture range. If this be so, flakeboard-core COM-PLY® will act elastically in LE_x but elastoplastically in LE_y, where the face veneers may undergo tangential restraint into the plastic range as in plywood.

Thus the appropriate predicting equation for LE_x for a flakeboard COM-PLY® is that for elastic action:

$$LE_x = FE_{\ell,f} + \frac{(FE_{t,c} - FE_{\ell,f})\, E_{t,c}}{E_{t,c} + E_{\ell,f}} \frac{T_c}{T_f}$$

For a 50-50 layup, with equal core and total face thickness, the T ratio becomes unity.

For LE_y, the appropriate equation will be either the equation for elastic action:

$$LE_y = FE_{\ell,c} + \frac{(FE_{t,f} - FE_{\ell,c})\, E_{t,f}}{E_{t,f} + E_{\ell,c}} \frac{T_f}{T_c}$$

or the equation for plastic action:

$$LE_y = FE_{\ell,c} + \frac{\sigma'_f}{E_{\ell,c}} \frac{T_f}{T_c}$$

whichever gives the lowest value of LE_y at the particular moisture condition under consideration.

Application of the LE theory in this form to the data we have on an aligned-flake core material, and on a commercial Douglas-fir faced COM-PLY® made from it, affords an opportunity to test the theory on an actual COM-PLY® material. We will first use the data from the Douglas-fir veneers of Phase 1 to compute predicted LE values for a hypothetical Douglas-fir faced COM-PLY® for comparison with the measured values of the similar but unmatched commercial COM-PLY®. The results are tabulated and plotted in Table 12 and Figure 16. The agreement is as good as might be expected with unmatched materials. The panel is extremely stable in the face-grain direction (LE_x), and less stable in the cross-grain direction (LE_y); however, even in the y direction, it is well within the range of stability encountered in plywood.

Samples of an *unsanded* aligned flakeboard core from the same COM-PLY® plant were also included in the experiment. These showed a negative linear expansion in the aligned direction at the higher moisture

Table 12. Measured core and face properties and calculated linear expansions from 30% RH of 1/2 in. COM-PLY with 1/8 in. Douglas-fir veneer faces and 1/4 in. sanded core of aligned flakes, at five moisture conditions. Measured LE values for a similar 1/2 in. COM-PLY are shown for comparison. Unmatched materials.

		Moisture Conditions				
	Number	1	2	3	4	5
	RH %	57	79	87	92	VP soak
Properties of 1/8 in. Douglas-fir faces	E_ℓ, 10^6psi	2.968	0.297	2.453	2.494	(2.494)
	E_t, 10^6psi	0.105	0.078	0.059	0.060	0.036
	FE_ℓ, in./in.	0.0004	0.0005	0.0006	0.0007	0.0010
	FE_t, in./in.	0.0125	0.0269	0.0350	0.0378	0.0491
	σ'_t, psi	1571	1291	1024	1017	617
Properties of 1/4 in. sanded oriented-flake core	E_ℓ, 10^6psi	1.011	0.886	0.743	0.700	0.626
	E_t, 10^6psi	0.271	0.230	0.185	0.171	0.167
	FE_ℓ, in./in.	0.0005	0.0009	0.0010	0.0011	0.0015
	FE_t, in./in.	0.0024	0.0051	0.0066	0.0075	0.0097
Calculated LE values for 1/2 in. COM-PLY.	LE_x %	0.06	0.09	0.10	0.11	0.16
	LE_y %	0.16	0.24	0.24	0.26	0.25
Measured LE values for 1/2 in. commercial COM-PLY	LE_x %	0.04	0.06	0.05	0.06	0.07
	LE_y %	0.10	0.21	0.25	0.25	0.33

levels. This is not unusual in boards of this flake geometry. Face and core properties and calculated linear expansion predictions are tabulated and plotted in Table 13 and in Figure 17. We have no data on actual COM-PLY® panels with unsanded cores for comparison—the plant uses only sanded cores. Such negative expansion usually occurs only on the first moisture increase, but it is stability in this first increase which is usually critical to successful panel performance in construction (an exception is stressed-skin panel construction).

As a final example of how the theory could be applied, let us consider how an *unaligned* flakeboard might perform as a COM-PLY® core and how changes in the T_f/T_c ratio affect the predicted stability. From the Phase 2 panels we will select the aspen waferboard as our hypothetical core material. This is an unoriented flakeboard having good flake geometry and relatively good stability; it has often been suggested as a promising candidate for COM-PLY® cores. Again, we will use the Douglas-fir veneer data for the faces.

Assuming first a 1/2 in. COM-PLY® with 1/8 in. Douglas-fir faces, and a 1/4 in. core of the aspen waferboard ($T_f/T_c = 1$), we calculate LE_x values using the elastic theory, and LE_y using the elastoplastic theory. The calculated values are shown in Table 14 and plotted in the upper and lower curves in Figure 18. The stability in the face-grain direction, LE_x, is similar to that of plywood, while LE_y is three to four times as great.

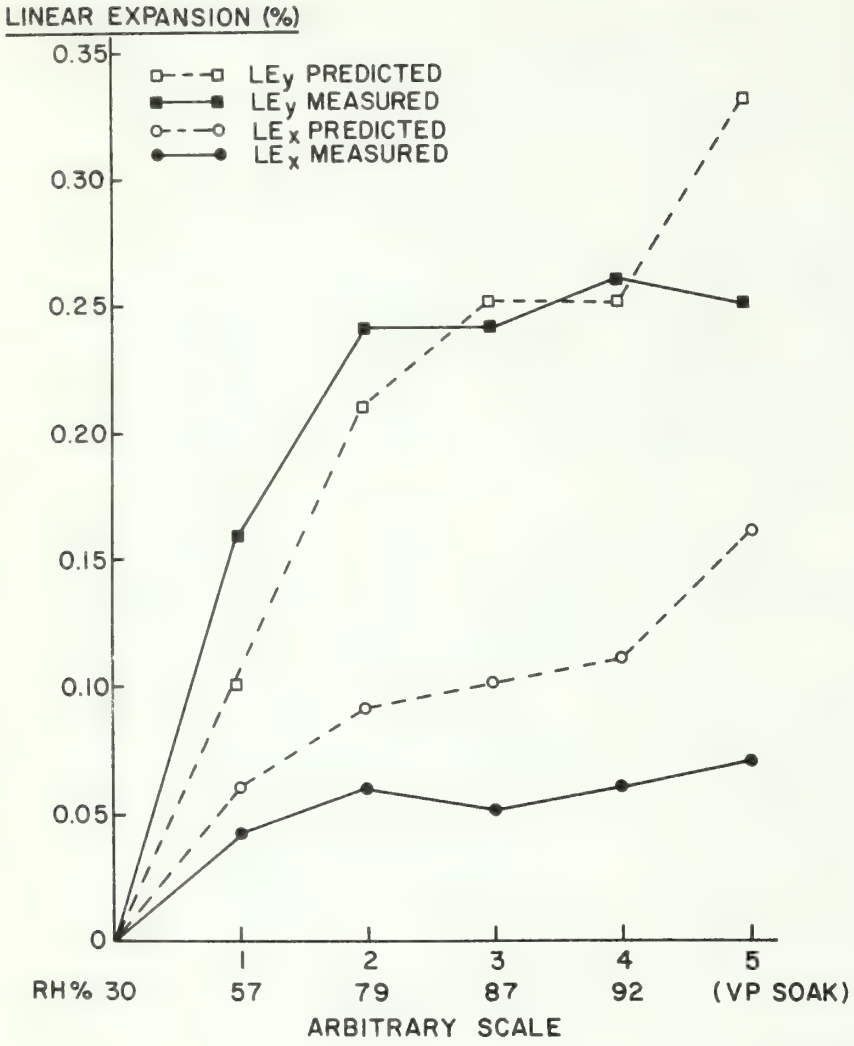


Figure 16. *Comparison of predicted and measured linear expansion from 30% RH for 1/2 in.* COM-PLY® *with 1/8 in. Douglas-fir veneer faces and 1/4 in. aligned-flake sanded core at five moisture conditions. Unmatched materials.*

If, instead, we assume a core thickness of 7/16 in. (the actual thickness of waferboard) and 1/10 in. faces ($T_f/T_c = 0.457$), the calculated LE_x and LE_y curves are now closer together. However, the small loss of stability in the x direction is accompanied by a large gain in stability in the y direction. At even lower T_f/T_c values the LE_x and LE_y curves would, of course, approach the average plotted LE curve of the waferboard core material itself (middle curve).

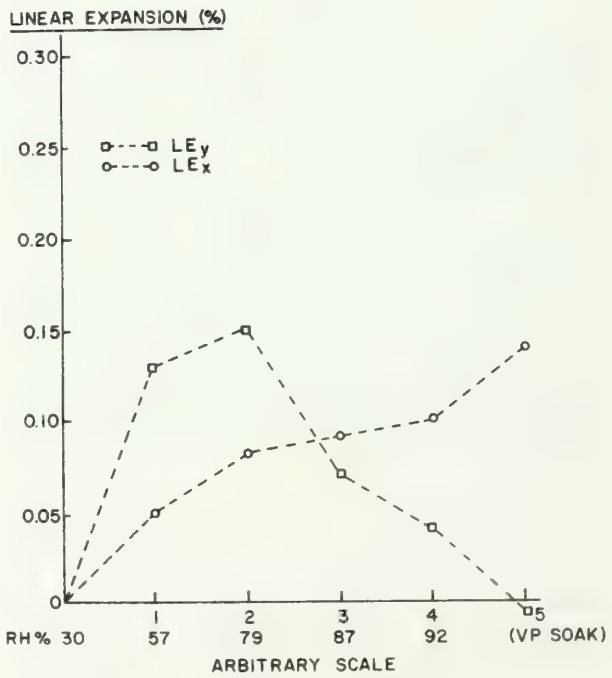


Figure 17. *Calculated linear expansions from 30% RH for 1/2 in.* COM-PLY® *with 1/8 in. Douglas-fir veneer faces and 1/4 in. unsanded oriented flake core. Compare with Figure 18.*

Table 13. Measured core and face properties and calculated linear expansions from 30% RH of hypothetical 1/2 in. COM-PLY with 1/8 in. Douglas-fir faces and 1/4 in. unsanded aligned flake core, at five moisture conditions.

	Number	1	2	3	4	5
	RH %	57	79	87	92	VP soak
Properties of 1/8 in. Douglas-fir faces	E_ℓ, 10^6psi	2.968	2.597	2.453	2.494	(2.494)
	E_t, 10^6psi	0.105	0.078	0.059	0.060	0.036
	FE_ℓ, in./in.	0.0004	0.0005	0.0006	0.0007	0.0010
	FE_t, in./in.	0.0125	0.0269	0.0350	0.0378	0.0491
	σ'_t, psi	1571	1291	1024	1017	617
Properties of 1/4 in. unsanded oriented-flake core	E_ℓ, 10^6psi	1.216	1.040	0.939	0.894	(0.894)
	E_t, 10^6psi	0.183	0.148	0.130	0.120	(0.120)
	FE_ℓ, in./in.	0.0003	0.0003	-0.00035	-0.0007	-0.0008
	FE_t, in./in.	0.0025	0.0058	0.0064	0.0081	0.0102
Calculated LE values for 1/4 in. COM-PLY.	LE_x %	0.05	0.08	0.09	0.10	0.14
	LE_y %	0.13	0.15	0.07	0.04	-0.01

Table 14. Measured face and core properties and calculated linear expansions from 30% RH of two lay-ups of COM-PLY having Douglas-fir faces and unoriented aspen waferboard cores, but having different ratios of face thickness to core thickness.

	Number	1	2	3	4	5
	RH %	57	79	87	92	VP soak
Properties of 1/8 in. Douglas-fir faces	E_ℓ, 10^6psi	2.97	2.60	2.45	2.50	(2.50)
	E_t, 10^6psi	0.105	0.078	0.059	0.060	0.036
	FE_ℓ, in./in.	0.0004	0.0005	0.0006	0.0007	0.0010
	FE_t, in./in.	0.0125	0.0269	0.0350	0.0378	0.0491
	σ'_t, psi	1571	1291	1024	1017	617
Properties of aspen waferboard core	E_ℓ, 10^6psi	0.803	0.708	0.636	0.603	0.469
	E_t, 10^6psi	0.728	0.644	0.577	0.544	0.424
	FE_ℓ, in./in.	0.0006	0.0011	0.0013	0.0015	0.0022
	FE_t, in./in.	0.0008	0.0051	0.0017	0.0019	0.0028
Calculated LE values for COM-PLY with 1/8 in faces & 1/4 in. core (T_f/T_c=1)	LE_x %	0.05	0.07	0.08	0.09	0.13
	LE_y %	0.20	0.29	0.29	0.32	0.35
Calculated LE values for COM-PLY with 1/10 in. faces and 7/16 in core(T_f/T_c=0.457)	LE_x %	0.06	0.09	0.11	0.12	0.16
	LE_y %	0.12	0.19	0.20	0.23	0.28

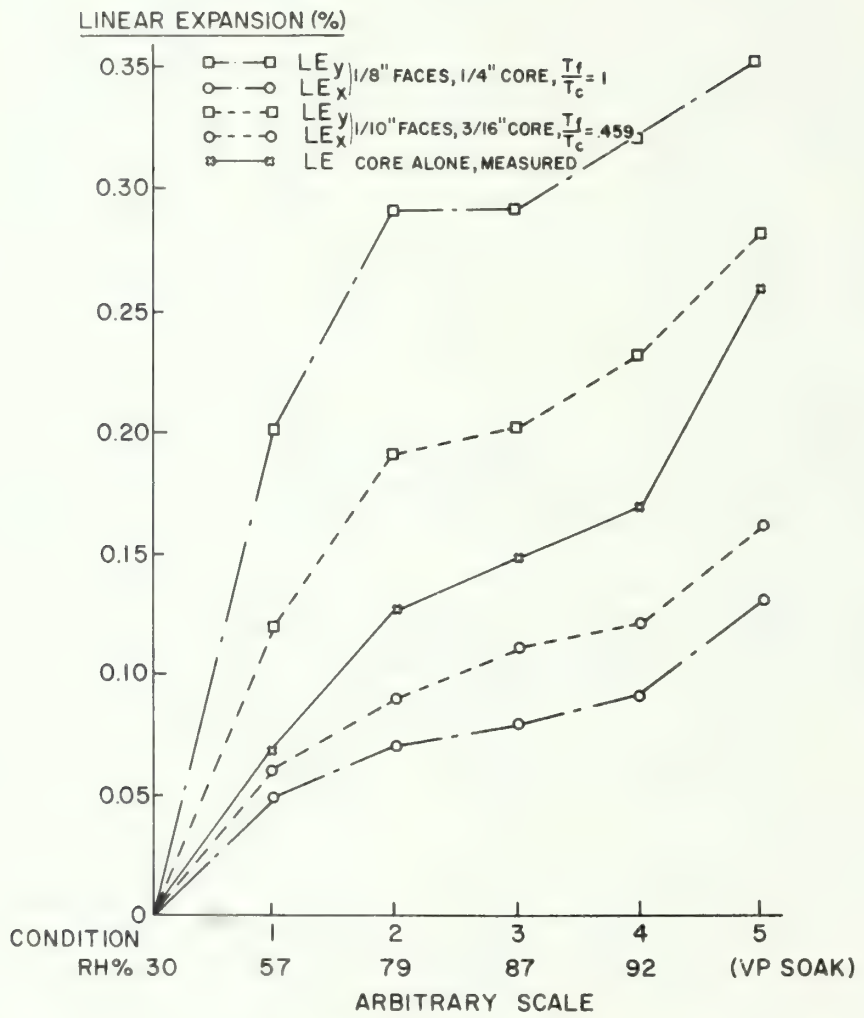


Figure 18. *Predicted linear expansion from 30% RH at five moisture conditions of hypothetical* COM-PLY® *with unoriented aspen waferboard cores and Douglas-fir faces, showing the effect of changing T_f/T_c ratio. The middle curve shows the average measured linear expansion of the core alone for comparison.*

CONCLUSIONS—PHASE 1

An improved theory of linear expansion has been developed which is applicable to both directions in plywood and COM-PLY® of any layup or combination of species and to the range of moisture content up to fiber saturation. Its advantage over previous elastic theory lies in its recognition that internal stresses in the board cannot exceed the corresponding strengths of the materials involved at the moisture conditions under consideration. The theory applies primarily to initial moisture increase with balanced moisture conditions on both sides of the panel, and requires knowledge of modulus of elasticity and free expansion in both directions for the materials of the different layers of the panel as a function of moisture conditions. For veneers, the lateral compressive strength is also required at moisture conditions at which predictions are needed.

In its present state, the theory slightly overestimates linear expansion at low moisture levels—probably because it does not take into account the effects of creep. Also, it is not directly applicable to the important practical situations of wetting from one side under restraint or to cyclic moisture changes.

An important early result of application of the theory is that particle alignment in COM-PLY® cores will be needed to achieve greatest stability in both directions. Particle alignment makes a double contribution to panel lateral stability: it greatly enhances the stability of the core in the panel y direction, and it increases the MOE of the core in the same direction. This reduces the amount that the core is stretched beyond its free expansion by the swelling forces of the face.

There is need for further basic research on lateral creep, or relaxation, in wood and particleboard under restraint as a function of moisture content. This will allow refinement of the stability theory and will enable its application to one-side wetting and to conditions other than initial wetting.

In conjunction with this, there is also need for further practical research with full-sized models on swelling of restrained decks (roof and floor) under one-side wetting using decking panels of plywood, COM-PLY® and particleboard whose unrestrained swelling characteristics have been previously evaluated both panelwise and by their component layers.

PHASE II.
INVESTIGATION OF APPROPRIATE REQUIREMENTS FOR DIMENSIONAL STABILITY OF STRUCTURAL PANEL MATERIALS UNDER MOISTURE CHANGES

INTRODUCTION

The demand for more fiber is the driving force for complete utilization of the forest. Other products will be in demand in the future, but for now, fiber is of highest priority. The U.S. Forest Service [29] estimated the potential growth of U.S. forests to be 95% greater than current growth (based on the merchantable stem). The level of forest productivity under intensive management, therefore, would be over twice the 1970 new removal. This estimate represents a maximum biological productivity of American forests under wide practice of present silvicultural technology, but it would take about 50 years to achieve. The projection of potential growth has been analyzed by others taking many factors into consideration [25] and noting different scenarios for the ultimate growth that will occur, but the potential for greatly increased growth is considerable.

However, whether any increased growth occurs will be governed by many socio-economic and institutional factors. It does appear that future supplies in the U.S. will have to be obtained from about the same forest base or an even smaller one than is now available, or else imports will have to be increased. Spurr and Vaux [25] pointed out that it will be difficult to attain full biological potential because of many factors, including high costs for growing timber on sites of lesser productivity and deliberately leaving areas unharvested for other uses such as recreation.

The delay in developing maximum biological productivity appears inevitable. All benefits from the forest, *e.g.*, timber, range, water and recreation, will have to be considered as a package, and the increase of one will constrain or reduce the output of another [5]. Worldwide, this same strategy is expressed for products [29] and for fuelwood [12].

To meet the need for new structural panel materials, a number of possibilities are available. Plywood, of course, will remain the dominant panel simply because it is widely accepted; mills exist to manufacture it, and supplies of veneer quality logs (even if many are of low quality) will be available to keep the same approximate level of plywood manufacture as at present. Providing the panels needed to meet the increased demand will require the manufacture of newer types of structural panels including composites, flakeboards made with thin flakes (0.015-0.020 in.), waferboards made with thicker flakes (about 0.030 in.), and particleboards made with smaller particles such as planer shavings. These three different types of composition boards will have high, intermediate, and lower static bending and dimensional stability properties, respectively. Composition boards and composite cores may or may not have their particles aligned. While medium density fiberboard (MDF) has not been considered for structural applications in the U.S. except as a combination sheathing/siding, it is now being used as a flooring panel in New Zealand. Whether this product invades the U.S. market remains to be seen.

Each panel type (or combination thereof) will have different end-use properties. It will behoove manufacturers to have a good understanding of each panel's properties and of the best building procedure to follow

for structural applications. All of these types of panels have been used successfully either in the U.S. or in other parts of the world. Their successes and failures are not all well known; thus, further information is needed for assisting their entrance into the U.S. market by the newer structural panels.

Although the research for this project is primarily concerned with COM-PLY®, much of it should be applicable in developing data on the other new structural panels.

Individual company financial feasibility studies should be made on all the choices of wood supply and products a company might manufacture. They would then have available the combinations with the greatest return on investment. Research conducted by the cooperator (U.S. Forest Service) on this project has developed such financial analysis programs for use by anyone interested.

RESEARCH APPROACH

The Phase 2 research attempted to determine appropriate requirements for linear stability in both directions of structural panel materials under moisture changes. The actual linear expansion performance was measured throughout the hygroscopic range for many types of panels. This included panels from the U.S. and from other parts of the world now being used successfully in structural applications. In addition, builders, building officials and code authorities were consulted in various parts of the U.S. to determine which means are currently being used to cope with moisture movement of panels. Pertinent literature on the subject was also reviewed.

LABORATORY PROCEDURE

Particleboard and two different composites were obtained from a variety of sources around the world. The boards represented a range of panels which can be used individually as structural panels or as cores for COM-PLY® . Not all types of particleboard were selected for this project; rather, representative panels were chosen. Other types of panels should fit within the range chosen for study.

Most of the panels were made with random particle alignment. The furnishes ranged from large flakes or wafers to small shavings-type particles. Several resins were used to bind these panels—from the standard urea and phenolic formulations to melamine-urea, melamine-phenolic, wattle tannin and radiata pine tannin. Also included for comparison were composites with aligned cores (phenolic resin binder), composites with random cores (isocyanate binder), and 4-ply CDX plywood in both Douglas-fir and southern pine. Four samples of each panel type were evaluated. All were 22 by 22 in. with a nominal thickness of 1/2 in. One set of West German panels, however, was 14 by 22 in. Table 15 describes the panels studied. Stress-wave E measurements were also taken on these samples. These data are available for other research but have not been included in this report.

The laboratory measuring systems utilized for linear expansion and stress-wave E were the same as used for the plywood evaluated in Phase 1. Also, the exposure to atmosphere at various relative humidities and the water soak were the same as in Phase 1 (Table 2). In fact, these specimens were run through the various test conditions with the Phase 1 specimens in order to save time and to have identical test conditions.

RESULTS AND DISCUSSION

Table 16 presents equilibrium moisture content data, linear expansion, and percent moisture absorption for the panels evaluated in Phase 2, through the five different changes in moisture exposure. Stress-wave E data are found in Table 17. The stress-wave

Table 15. Descriptive data on panels evaluated for the Phase 2 research.

Study No. and Name		Binder	Country
1	Flakeboard	Urea	Australia
2	Flakeboard	Urea	United Kingdom
3	Flakeboard	Urea	New Zealand
4	Flakeboard*	melamine-urea	W. Germany
5	Flakeboard	melamine-phenol	W. Germany
6	Flakeboard	phenol	W. Germany
7	Waferboard	powdered phenol	Canada
8	Flakeboard	radiata tannin (experimental)	New Zealand
9	Flakeboard	wattle tannin	Australia
12	Composite with aligned core	phenol	U.S.
13	Composite with random core	isocyanate	U.S.
14	Plywood 4-ply (CDX) Douglas-fir	exterior glue	U.S.
16	Plywood, 4-ply CDX, Southern pine	exterior glue	U.S.

*Panel size 14 by 22 in. All others were 22 by 22 in. Flakeboards were mostly of 3-layer or multi-layer construction with the finer material on the faces.

E data are not of much value in the Phase 2 research; however, they should be of great value in the buckling-factor research being conducted by APA.

Variations in equilibrium moisture content result from varying levels of binder, types of binder, and chemical additives, as well as some probable heat treating which occurs during hot pressing. This was discussed earlier under Phase 1. The linear expansion data obtained are illustrated graphically in Figures 19-31 (30% RH to soak). Figure 32 compares most of the panels evaluated. These data show a slight range of linear expansion as would be expected. Some suspected machine direction is apparent in randomly formed panels, but the variation in linear expansion in the two directions is relatively small.

Plywood shows the lowest linear expansion in both directions because of its 4-ply construction, followed by composite with aligned core, waferboard, the various particleboards from throughout the world, and finally the composite with randomly formed core. This latter panel had the lowest linear expansion in the grain direction of any product but the highest expansion across the grain.

The unrestrained linear expansions, however, do not directly relate to what happens in the field. Further discussion on the relationship of these tests to field practice will be reserved for the general discussion at the end of this section of the report covering Phase 2.

Table 16. Phase 2 panel material percent linear expansion, percent moisture absorbed from equilibration at 30% Rh and equilibrum moisture content at five moisture conditions.

Study No. & Name	Observation	Relative Humidity %					Vacuum Pressure Soak
		30	57	79	87	92	
1	LE_1*		0.12	0.23	0.29	0.34	0.68
Urea flake-	LE_2*		0.10	0.19	0.23	0.28	0.53
board	%MA		2.2	4.9	7.2	8.5	92
(Australia)	EMC	8.4	10.7	13.7	16.2	17.5	108
2	LE_1		0.16	0.28	0.35	0.40	0.77
Urea flake-	LE_2		0.14	0.24	0.29	0.34	0.65
board (U.K.)	%MA		2.4	5.2	7.5	8.7	79
	EMC	8.3	10.9	13.9	16.4	17.7	93
3	LE_1		0.12	0.21	0.24	0.28	0.43
Urea flake-	LE_2		0.10	0.18	0.21	0.24	0.36
board (N.Z.)	%MA		2.0	4.3	6.2	7.3	75
	EMC	8.4	10.6	13.1	15.2	16.4	90
4	LE_1		0.18	0.29	0.33	0.35	0.50
Melamine-urea	LE_2		0.151	0.25	0.27	0.30	0.41
flakeboard	%MA		2.7	4.7	6.0	6.8	62
	EMC	8.7	11.6	13.8	15.1	16.0	76
5	LE_1		0.15	0.23	0.28	0.31	0.41
Melamine-phenol	LE_2		0.13	0.21	0.24	0.28	0.36
flakeboard	%MA		2.4	5.0	7.4	9.1	70
	EMC	9.1	11.7	14.5	17.2	19.0	86
6	LE_1		0.15	0.26	0.31	0.34	0.43
Phenolic flake-	LE_2		0.14	0.24	0.29	0.31	0.40
board	%MA		2.8	7.8	13.0	16.9	72
	EMC	11.3	14.4	20.0	25.8	30.1	92
7	LE_1		0.08	0.14	0.17	0.19	0.28
Waferboard	LE_2		0.06	0.11	0.13	0.15	0.22
	%MA		3.1	7.5	10.6	12.2	120
	EMC	5.2	8.4	13.1	16.3	18.1	132
8	LE_1		0.13	0.24	0.29	0.33	0.57
Radiata tannin	LE_2		0.11	0.20	0.24	0.28	0.47
flakeboard	%MA		2.3	5.8	8.6	9.9	80
	EMC	7.9	10.4	14.1	17.2	18.6	94
9	LE_1		0.14	0.24	0.27	0.31	0.48
Wattle tannin	LE_2		0.13	0.21	0.23	0.27	0.42
flakeboard	%MA		3.1	5.9	8.2	9.8	80
	EMC	10.3	13.7	16.7	19.2	21.0	99

Table 16. (continued)

Study No. & Name	Observation	Relative Humidity % 30	57	79	87	92	Vacuum Pressure Soak
12	LE_1		0.10	0.21	0.25	0.25	0.33
Composite with	LE_2		0.04	0.06	0.05	0.06	0.07
aligned core	%MA		3.31	8.4	11.4	13.5	80
(phenol)	EMC	7.8	11.4	16.9	20.1	22.4	94
13	LE_1		0.37	0.73	0.80	0.89	1.49
Composite with	LE_2		0.02	0.04	0.04	0.04	0.07
random core	%MA		--	4.6	7.6	8.9	62
(isocyanate)	EMC	--	11.2	16.2	19.6	21.1	85
14	LE_1		0.06	0.08	0.072	0.08	0.13
Plywood, 4-ply	LE_2		0.05	0.07	0.054	0.06	0.09
CDX, Douglas-fir	%MA		2.8	7.8	10.6	12.2	82
	EMC	5.9	8.8	13.8	17.1	18.8	9.3
16	LE_1		0.05	0.06	0.07	0.08	0.10
Plywood, 4-ply	LE_2		0.07	0.07	0.04	0.04	0.08
CDX, Southern	%MA		3.0	7.2	10.2	11.8	72
pine	EMC	7.9	11.1	15.6	18.9	20.8	85

* LE_1: Linear expansion measured across fiber alignment or suspected machine direction.
LE_2: Linear expansion measured parallel to fiber alignment or suspected machine direction.

LITERATURE AND FIELD SURVEY

Various types of particleboard have been used structurally throughout the world. Thus, valuable field experience is available for use in this research. Unfortunately, much of the experience has yet to find its way into the literature, making it difficult to take full advantage of such experience.

This section of the report covers specifications for use of structural panels in the U.S. and Canada. Recent literature is then reviewed which covers North American and overseas experience with composites and particleboards.

Next reported are the results of consultations with builders, building officials, code authorities, and panel manufacturers which were conducted to determine the means currently being used to cope with the movement of panels caused by moisture changes. The thrust of this investigation was to see if the industry was using the structural panels according to specifications, which has not always been the case in the past.

The experience of three of the co-principal investigators having extensive building backgrounds has been that specifications for handling panel movement due to moisture changes (spacing around panels) are usually ignored. Thus, they were interested in determining if the building industry had changed to installing panel products according to specifications or if the industry was still ignoring them.

Numerous field studies were made, namely in Ohio, Missouri, Louisiana, western Washington, and in the local Pullman, Washington area. In addition, several phone and individual consultations were made and

Table 17. Phase 2 panel materials. Stress wave E data for both panel directions at six relative humidity conditions.

Study No. and Name	Observation	Relative Humidity % 30	57	79	87	92	Vacuum Pressure Soak
1	MOE_1*	0.691	0.716	0.666	0.602	0.553	0.335
Urea flakeboard	MOE_2*	0.585	0.604	0.561	0.508	0.475	0.274
(Australia)	MOE_1/MOE_2	1.18	1.19	1.19	1.19	1.16	1.22
2	MOE_1	0.556	0.564	0.545	0.498	0.467	0.337
Urea flakeboard	MOE_2	0.517	0.512	0.454	0.447	0.421	0.302
(United Kingdom)	MOE_1/MOE_2	1.08	1.10	1.20	1.11	1.11	1.12
3	MOE_1	0.710	0.729	0.706	0.672	0.639	0.482
Urea flakeboard	MOE_2	0.655	0.658	0.628	0.597	0.566	0.426
(New Zealand)	MOE_1/MOE_2	1.07	1.12	1.12	1.13	1.13	1.13
4	MOE_1	0.410	0.540	0.522	0.505	0.489	0.456
Melamine-urea	MOE_2	0.384	0.529	0.505	0.505	0.490	0.444
flakeboard	MOE_1/MOE_2	1.07	1.02	1.03	1.00	1.00	1.03
5	MOE_1	0.569	0.592	0.544	0.508	0.475	0.421
Melamine-phenol	MOE_2	0.527	0.549	0.510	0.471	0.439	0.390
flakeboard	MOE_1/MOE_2	1.08	1.08	1.07	1.08	1.08	1.08
6	MOE_1	0.602	0.595	0.494	0.413	0.376	0.357
Phenolic	MOE_2	0.564	0.559	0.463	0.387	0.356	0.337
flakeboard	MOE_1/MOE_2	1.07	1.06	1.07	1.07	1.06	1.06
7	MOE_1	0.767	0.803	0.708	0.636	0.603	0.469
Waferboard	MOE_2	0.687	0.728	0.644	0.577	0.544	0.424
	MOE_1/MOE_2	1.12	1.10	1.10	1.10	1.11	1.11
8	MOE_1	0.666	0.692	0.629	0.576	0.541	0.405
Radiata Tannin	MOE_2	0.601	0.619	0.562	0.515	0.482	0.360
Flakeboard	MOE_1/MOE_2	1.11	1.12	1.12	1.12	1.12	1.13
9	MOE_1	0.601	0.608	0.574	0.537	0.509	0.382
Wattle Tannin	MOE_2	0.548	0.543	0.517	0.478	0.451	0.338
	MOE_1/MOE_2	1.11	1.12	1.11	1.12	1.13	1.13
12							
Composite with	MOE_1	1.783	1.776	1.650	1.624	1.634	1.746
aligned core	MOE_2	0.619	0.631	0.581	0.522	0.501	0.444
(phenol)	MOE_1/MOE_2	2.88	2.81	2.84	3.11	3.26	3.93
13							
Composite with	MOE_1	--	1.381	1.281	1.219	1.108	1.198
random core	MOE_2	--	0.356	0.310	0.240	0.261	0.228
(isocyanate)	MOE_1/MOE_2	--	3.88	4.13	5.08	4.25	4.82
14	MOE_1	1.380	1.435	1.386	1.344	1.331	1.343
Plywood, 4-ply,	MOE_2	0.852	0.901	0.873	0.819	0.818	0.838
CDX, Douglas-fir	MOE_1/MOE_2	1.62	1.59	1.59	1.64	1.63	1.60
16							
Plywood, 4-ply	MOE_1	1.509	1.516	1.463	1.426	1.4124	1.517
CDX, Southern	MOE_2	1.104	1.110	0.946	1.045	1.000	1.071
pine	MOE^1/MOE^2	1.37	1.37	1.55	1.36	1.41	1.42

*MOE_1: Measured parallel to orientation.
MOE_2: Measured perpendicular to orientation.

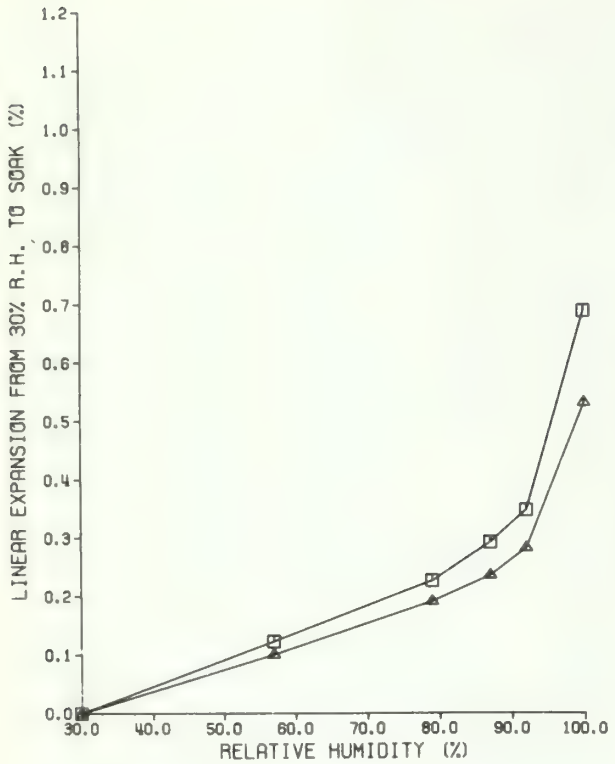


Figure 19. *Linear expansion of Australian urea flakeboard from 30% RH as a function of RH in both panel directions.*

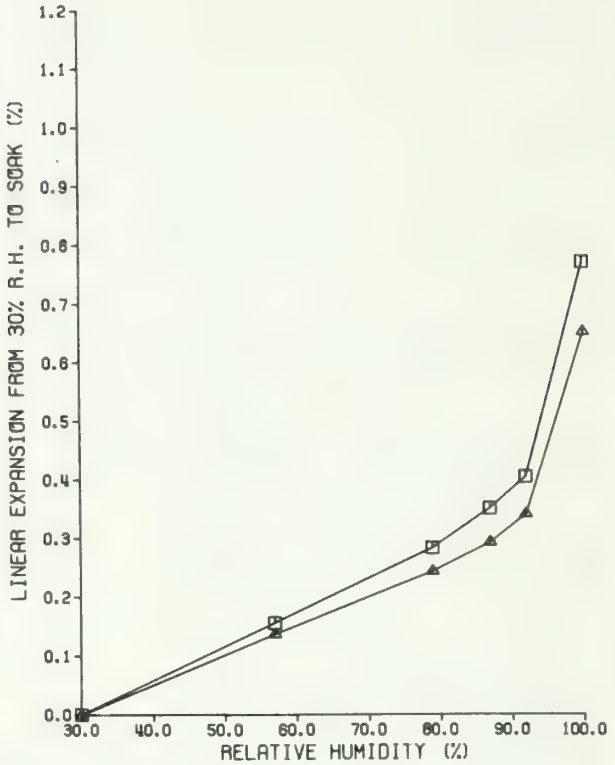


Figure 20. *Linear expansion of United Kingdom urea flakeboard from 30% RH as a function of RH in both panel directions.*

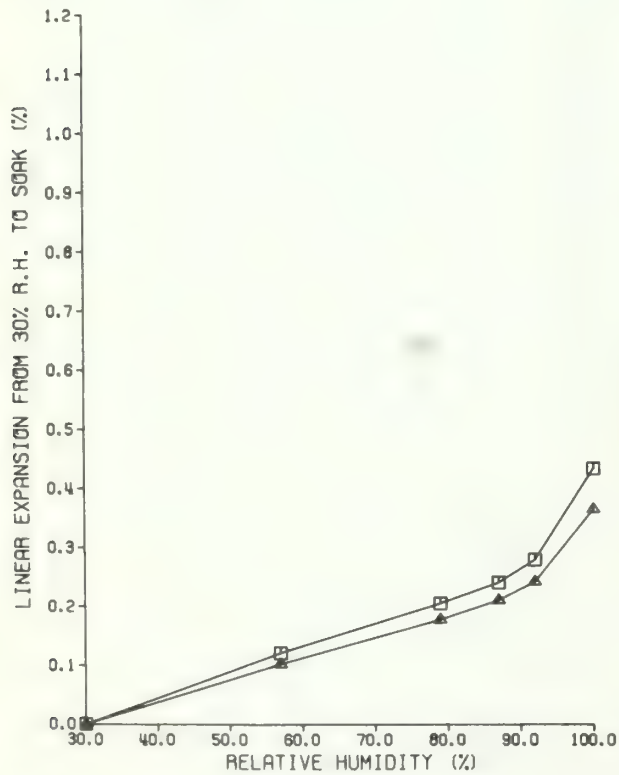


Figure 21. *Linear expansion of New Zealand urea flakeboard from 30% RH as a function of RH in both panel directions.*

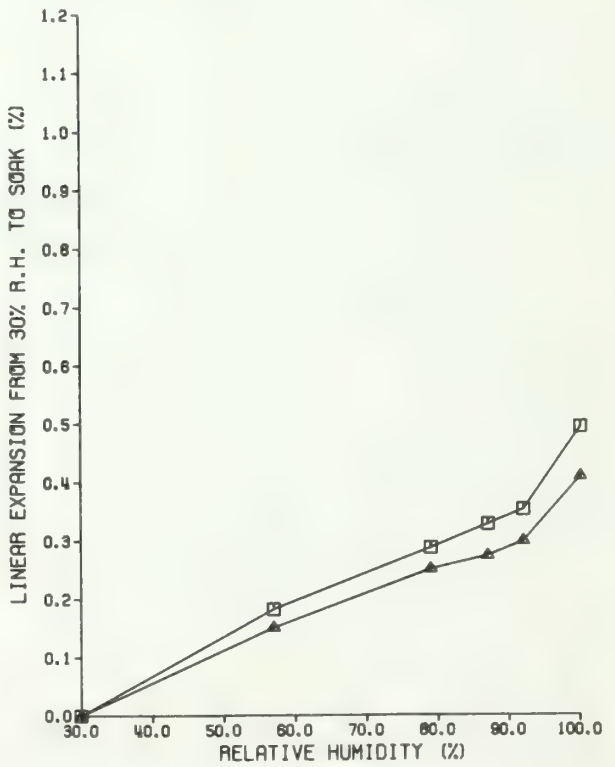


Figure 22. *Linear expansion of West German melamine-urea flakeboard from 30% RH as a function of RH in both panel directions.*

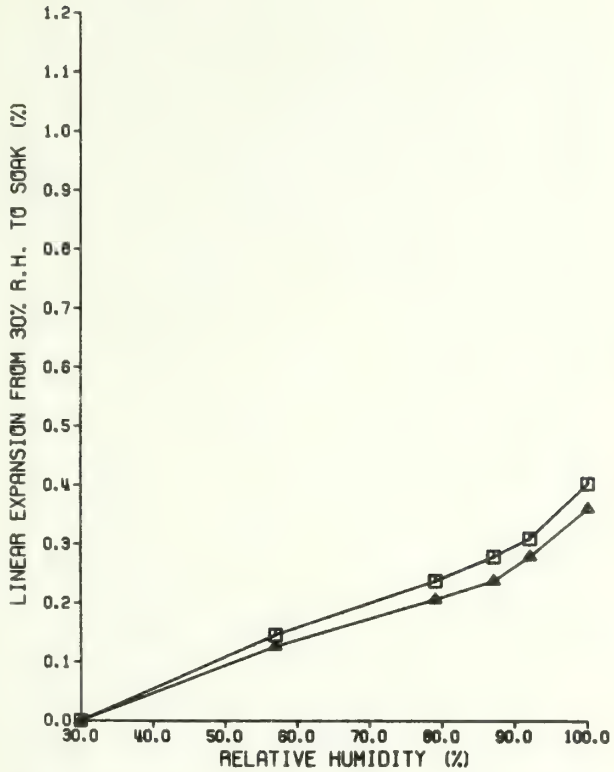


Figure 23. *Linear expansion of West German melamine-phenol flakeboard from 30% RH as a function of RH in both panel directions.*

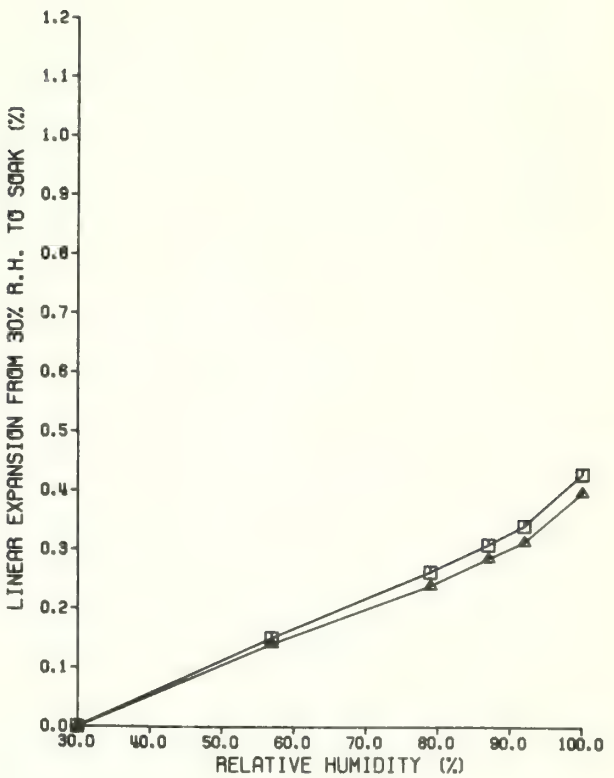


Figure 24. *Linear expansion of West German phenol flakeboard from 30% RH as a function of RH in both panel directions.*

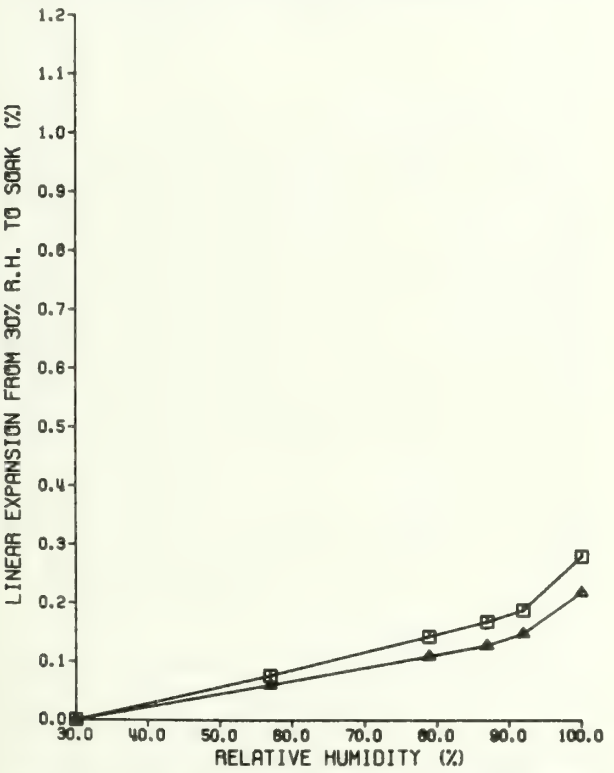


Figure 25. *Linear expansion of Canadian phenol waferboard from 30% RH as a function of RH in both panel directions.*

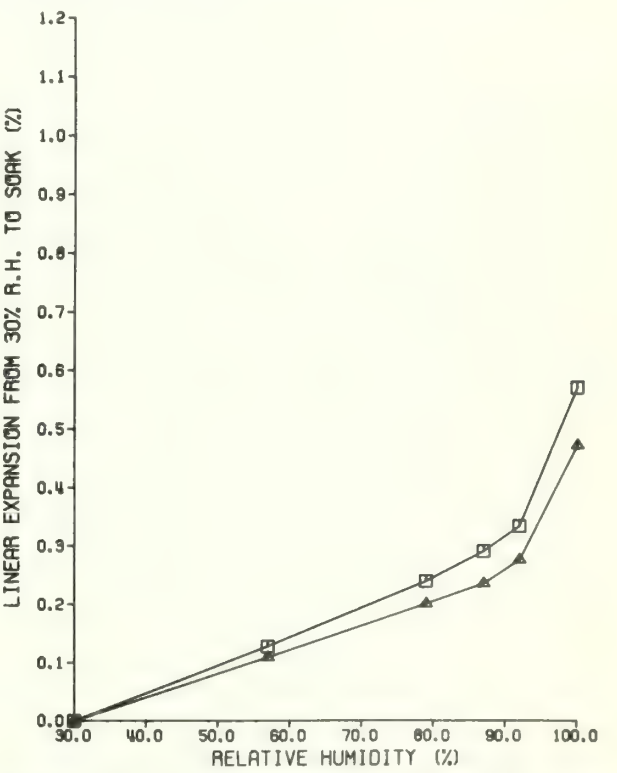


Figure 26. *Linear expansion of New Zealand* Radiata *tannin flakeboard (experimental) from 30% RH as a function of RH in both panel directions.*

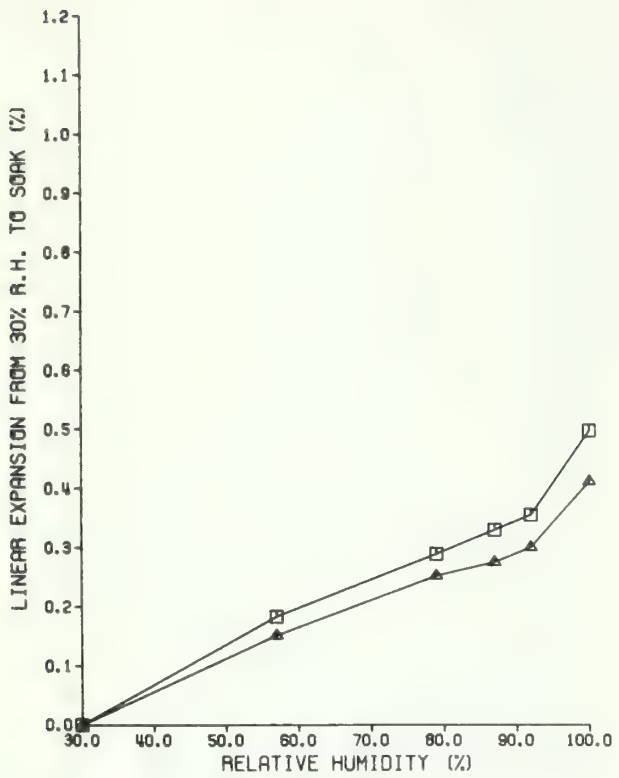


Figure 27. *Linear expansion of Australian wattle-tannin flakeboard from 30% RH as a function of RH in both panel directions.*

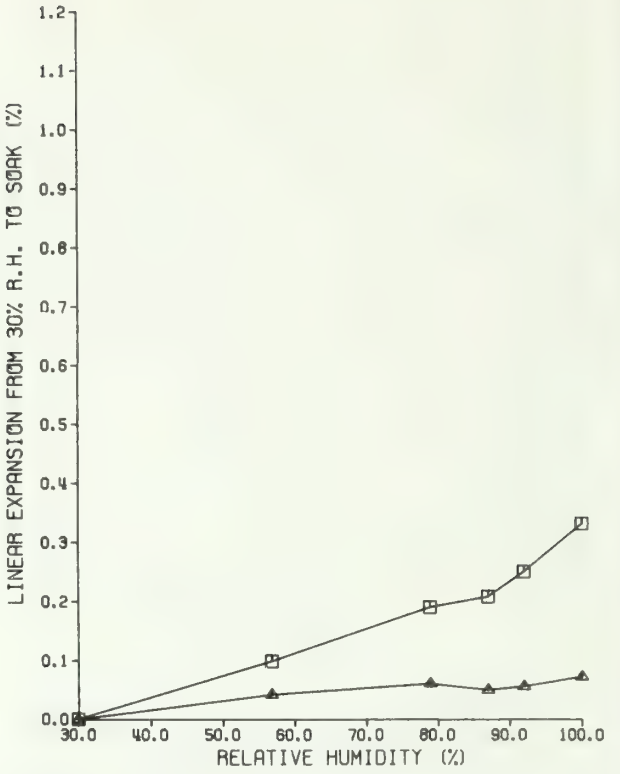


Figure 28. *Linear expansion of United States aligned-core phenol composite from 30% RH as a function of RH in both panel directions (△ - veneer direction; - core direction).*

recent literature on the subject was reviewed. This part of the report will summarize the information obtained and make generalized conclusions. The study was not designed to be a comprehensive study of all parts of the country, as such a study would be very expensive. Instead, the work was conducted as spot surveys of current practices.

Details of the construction of a "Conservation House" utilizing composites with oriented flake cores and observations on the use of COM-PLY® in this house are included as part of this report. The final section of the report covers general conclusions.

Specifications

Several documents were reviewed to determine how the builder was being instructed to use structural panel products. The American Plywood Association (APA) and the Canadian government were very specific on the subject. Recently, the Department of Housing and Urban Development, Federal Housing Administration (FHA), has started to put installation specifications into their "Use of Materials" bulletins, which is a change from the past. Building Code manuals are not including such specifications, but it is their intent that good building practices should be utilized based on details provided by manufacturers, associations and government agencies.

American Specifications

American Plywood Association. Some of the various APA specifications relative to panel spacing are as follows (from *Plywood Construction Guide*, Nov. 1978):

Roof Sheathing (p. 30): 1/16 in. space at end joints, 1/8 in. at edge joints; double these spacings under wet and humid conditions.

Sturd-I-Floor (p. 10): 1/16 in. space at all edge and end joints (3/32 in. at T&G edges) except for 2-4-1 panels which are to be spaced 1/16 in. in all cases. 2-4-1 is 1-1/8 in. thick plywood.

Glued Floor System (p. 13): 1/16 in. space at all end and edge joints (3/32 in. at T&G edges of panels less than 1-1/8 in.).

Subfloor (p. 15): Same as for roof sheathing.

Underlayment (p. 16): 1/32 in. space for all butt joints.

Single Wall Siding (p. 20): 1/16 in. space at end and edge joints.

Siding over Sheathing (p. 22): 1/16 in. space at end and edge joints.

Wall Sheathing (p. 23): Same as for roof sheathing.

Interior Paneling (p. 27): 1/32 in. space at panel edges.

Soffits (p. 32): 1/16 in. space at all end joints, 1/8 in. at edge joints. Edge spacing may be reduced to 1/16 in. if joint will be visible.

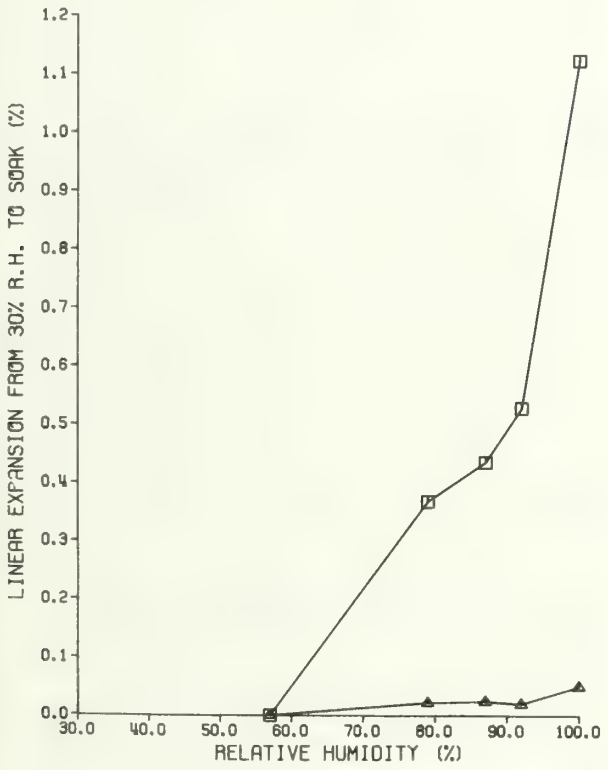


Figure 29. *Linear expansion of United States isocyanate random-core composite from 30% RH as a function of RH in both panel directions (△ - veneer direction; □ - core direction).*

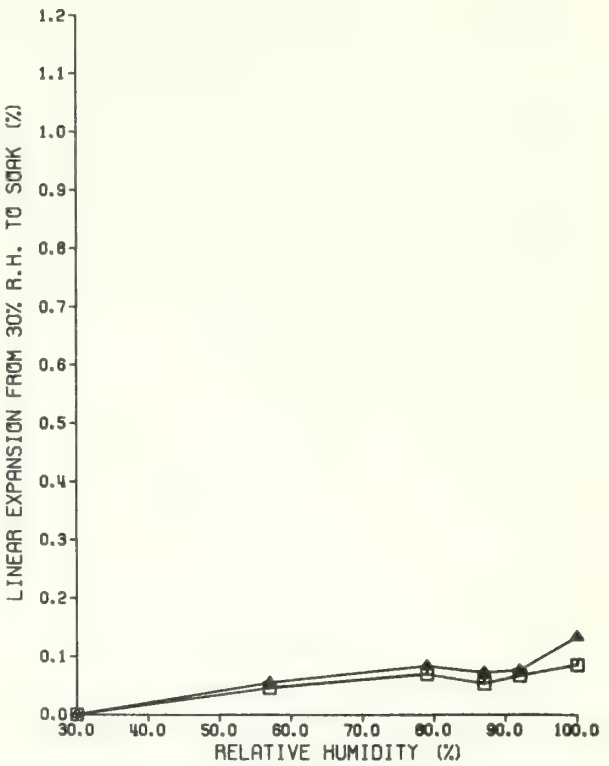


Figure 30. *Linear expansion of United States CDX Douglas-fir 4-ply plywood from 30% RH as a function of RH in both panel directions.*

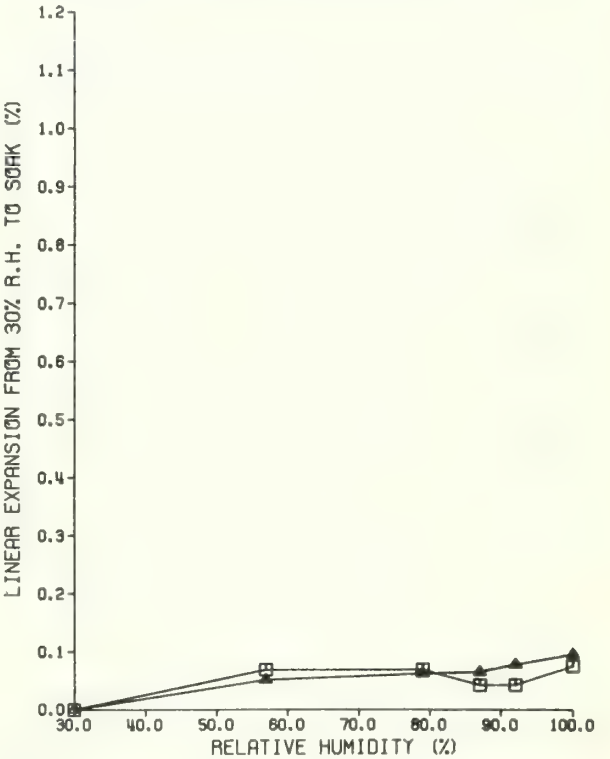


Figure 31. *Linear expansion of United States CDX southern yellow pine 4-ply plywood from 30% RH as a function of RH in both panel directions.*

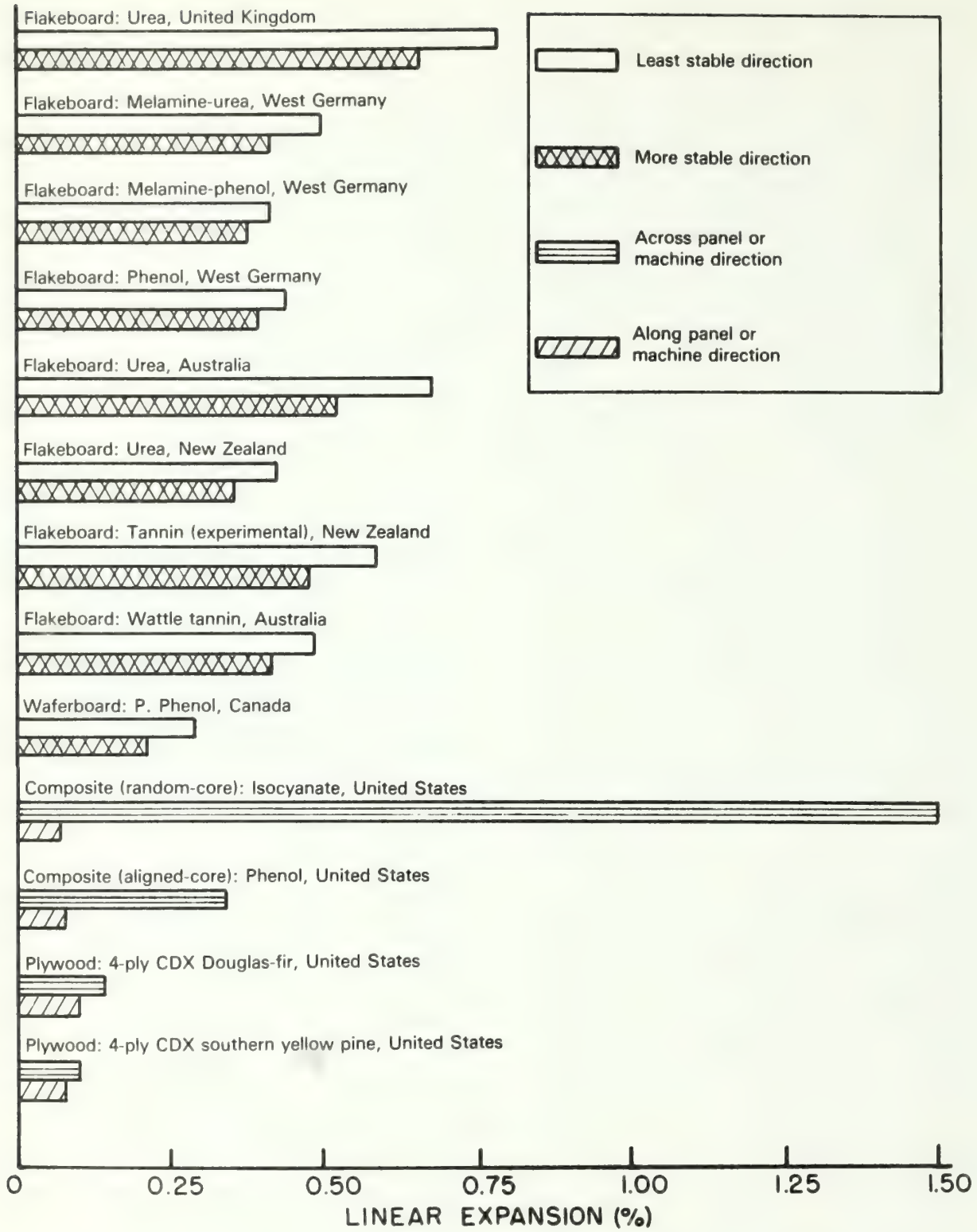


Figure 32. *Linear expansion from 30% RH equilibrium to soak for various structural panel materials currently in use.*

Federal Housing Administration. Use of Materials Bulletin No. 66a, dated December 6, 1978, is entitled, "Plywood Combination Subfloor/Underlayment Floor Panels." Under Section 3.2, Installation, it calls for the following [28]:

> Space the panel end joints 1/16 in. Space the panel edge joints 3/32 in. If wet conditions are anticipated, provide up to 1/16 in. of additional spacing at the edges and ends.

Spacing is called for in Use of Materials Bulletin No. 64b, "Textured Plywood Panel Siding," dated August 13, 1975. Under Section 3.2, Installation, it states in part [27]: "...panels shall be spaced 1/16 in. apart at the joints."

Canadian Specifications

Residential Standards, Canada, 1977, NRCC No. 15563. The following information was found in this document [22]:

Under Wood Frame Construction—Sec. 23, p. 79:

(para 0[3]): "Particleboard and plywood sheathing shall be installed with at least 1/16 in. gap between sheets." (Roof sheathing)

(para P[5]): "A gap of not less than 1/16 in. shall be left between sheets of plywood, particleboard or fiberboard." (Wall sheathing)

There is no such gap requirement in Section N on subflooring.

Section 28 on Siding (para I on Plywood):

(para I[4]): "Not less than 1/16 in. gap shall be provided between sheets."

(para I[5]): "Plywood applied in horizontal lapped strips shall have not less than 1/16 in. gap provided at the butted ends *which shall be caulked.*"

(para J on Hard-Pressed Fiberboard):

(para J[3]): "Not less than 3/16 in. gap shall be provided between sheets.

(para J[4]): "Hard-pressed fiberboard applied in horizontal lapped strips shall have not less than a 3/16 in. gap provided at the butted ends which shall be caulked or otherwise protected with suitable mouldings."

(para J[5]): "At least a 1/8 in. clearance shall be provided between hard-pressed fiberboard siding and door or window frames."

Para K on Particleboard:

(para K[3]): "Not less than a 1/8 in. gap shall be provided between sheets."

(para K[4]): "At least a 1/8 in. clearance shall be provided between particleboard siding and door or window frames."

Section 31, Flooring: There is no prescription for gaps in flooring or interior finish products. It appears as if the concern is only for parts of the building that may be exposed to weather.

There are no similar spacing requirements for cement asbestos board, metal or vinyl materials. The specifications appear to be for dimensional problems with wood materials only.

Building Conference Groups

An approach for moving a product into the construction market is to apply to a building code group such as the International Conference of Building Officials (ICBO) or the Building Officials and Code Administrators International, Inc. (BOCA). An independent testing agency supplies them with research and technical data on the product in question. This information is then acted upon, and a research committee recommendation (ICBO) or a research report (BOCA) is issued for use by building officials or other authorities having jurisdiction in areas covered by the building officials groups.

Waferboard and phenolic-bonded shavings type particleboard have been approved for structural use by this approach. A research report has been issued by BOCA [9] covering waferboard produced by Blandin Wood Products Co., for use as roof and wall sheathing. Panels are to be spaced 1/8 in. apart to allow for expansion.

A Research Committee Recommendation has been issued covering Redex Particleboard [15]. This shavings type board can be used for roof and floor sheathing when protected by an approved weatherproof surfacing material. Panels are to be installed with a 1/8 in. gap at all panel edges.

Recent Literature

Potlatch Development

The Potlatch Corporation has developed, and now manufactures, a composite panel product. It is reportedly functioning the same as plywood in the marketplace. Early work, however, concentrated on a three-ply oriented flakeboard with the plies layed up as in plywood. Field trials conducted by Bean and Brown in 1974 [4] covered reactions to linear dimensional stability along and across the panel, thickness swell, and shorter allowable spans for roof sheathing than plywood. The following statement refers to its use as sheathing:

> No problems were caused anywhere in the trials due to linear dimensional stability problems even though, in most applications, the recommendations on panel spacing were ignored by the applicators. Excessive instability usually shows up in the panel buckling along or across the panels. None of this was evidenced in the field trial program even though several applications were left exposed to the weather for several weeks during which heavy rains occurred.
>
> Edge swelling was noticed by a couple of applicators but was not considered serious for sheathing purposes. Otherwise, there were no comments on general thickness swell.

It was found that the product was technically suitable for sheathing purposes, particularly as far as strength, stiffness, and dimensional stability were concerned.

Surveys by R. N. Jorgenson

R. N. Jorgenson in 1975 [16] reported personal observations during a field survey of users of structural particleboard. He reported the following problems:

Floor squeaking, with and without mastic glue.
Weight, requires increased truss strength for roofs.
Impact breakage (only during construction).
Edge breakage (during construction).
Swelling (when exposed to standing water).
Fastening (harder to nail).
Nothing given on expansion gaps.
Need to provide some construction crew orientation.
Spot swelling.

The good points observed were:

No delamination and good durability.
No voids in the core.
Two-way stiffness (but one contractor thought this was a disadvantage because shrinking joists pulled away from the board). Most liked this property.

Mr. Jorgenson also supplied us with copies of his trip reports for August 1973, January and June 1974, and August 1975, which covered the use of waferboard. Where clips were used providing expansion gaps for roof sheathing, no difficulties were encountered even when panels had been exposed to inclement weather for some time. One house went through a hard winter with no roofing over the waferboard sheathing without noticeable damage.

One builder shifted to using a shavings type exterior particleboard sheathing rather than interior type plywood sheathing because of delamination problems with the plywood. When builders changed to structural panels other than plywood, however, lower prices were usually given as the reason.

Builders did have problems with highly objectionable panel breakage during construction. This was found with both waferboard and particleboard sheathing type panels.

Western Canadian Laboratory Research

In 1979, Kasper and Carroll [17] investigated buckling problems with shavings type (phenolic bonded particleboard) decking. Experimental floors were built in 12 by 12 ft. sections. Under extreme conditions of wetting from one side (MC ranging from

54% in the top third to 34% in the bottom third), decking which was nailed down (restrained) did not significantly distort or buckle. One floor was built without expansion gaps at the ends. The edges were tongue and groove (T&G). The overall dimension of the floor increased by about 0.25%. Upon drying, gaps approximately 0.160 in. were formed at the T&G joints. The butt joints formed on the joists did not open, indicating that the nailing had provided adequate restraint to panel movement.

The most interesting observation was that 62% of the linear expansion inherent in the panels was absorbed internally. Compression across the face of the panels was developed, but panel buckling did not occur.

In light of these findings, Kasper and Carroll recommend that a given board with no history of use should be evaluated in actual use to determine if there are buckling problems. Once it is established that the panel will serve well, linear expansion tests should be used for quality control. Maximum linear expansion limits would be governed by those of the boards subjected to the full scale testing.

ELCOBOARD®

The ELCOBOARD® composite (randomly formed cores with veneer faces, bonded with isocyanate resin) has undergone many years of research, development and field trials. Braun and Ellingson [6] discuss in their most recent paper the extensive testing program that has been carried out.

Field reports indicate user satisfaction. Tests with floor sections 16 ft square, exposed to the elements or sprinkled with water for 14 days, showed no problems with excessive linear expansion. Panels were 1/2 in. thick and were applied according to the manufacturer's specifications of 1/16 in. gaps between panels at their ends and 1/8 in. gaps between panels at their edges. Nailing was with 6-penny common nails spaced at 6 in. intervals around the panel perimeter and 10 in. on intermediate supports.

Overseas Experience

Particleboard has been used for floor, roof and wall sheathing, concrete form, and other building applications in many parts of the world. The most notable places which use the panels similarly to U.S. practice are Australia, New Zealand, and Western Europe.

Australia. Australia has two grades of flooring particleboard: Classes 1 and 2. Class 1 has a phenolic type binder and Class 2 has a urea type binder [2]. There is also the Australian Standard 1860-1976, "Installation of Particleboard Flooring" [3].

Platform flooring is butted together in application so that no gaps are left between panels. The standard recommends that the flooring be protected from the elements as soon as possible after fixing, and that

> ...under no circumstances shall the exposure time limits recommended by the particleboard manufacturer be exceeded. Any ponded water resulting from exposure of the flooring to rain shall be removed as soon as practical.

Softwood Holdings Ltd. [24] limits exposure of their Class 2 (urea bonded) panel to 8 weeks.

One of the co-principal investigators has visited Australia and has observed this flooring in use. There were no apparent problems with linear expansion.

New Zealand. Urea bonded flooring particleboard has been used in platform construction for a number of years. Pollard [23] traced its development. Sealants on edges and on the underside were considered necessary at first but were later found to be unnecessary. These boards are made with relatively thin flakes (random formation). Although linear expansion specifications are not given, a water absorption of less than 7% in one hour is required.

About 80% of the new housing in New Zealand has particleboard floors. It is classed as high density at 43 ± 2.5 lbs/ft^3 (this would be medium density in the U.S.). Panels are about 6 by 12 ft in size, requiring two people to handle them. However, their large size makes it possible to lay a floor quickly. Threaded galvanized nails driven at a slight angle are recommended for installation. This type of floor is also used for offices and large rooms such as gymnasiums. They are covered with tile or similar materials or finished with a clear varnish or urethane material.

The floor panels are butted together without gaps. Considerable rainwater can fall on a floor while a building is under construction in New Zealand. One of the co-principal investigators has observed floors that had several inches of rainwater fall on them without significant buckling, edge swell, or surface roughening.

Recent company literature [10] instructs installers that floors are not to be exposed to the elements for more than eight weeks and that ponded water is to be removed immediately. No linear expansion values were given for this product (a medium density fiberboard), and no gaps between panels were specified.

Western Europe. Particleboard is being used more extensively every year in western Europe for structural purposes. Floors, roofs and prefabricated elements are all made from particleboard. Concrete forms are another structural use.

In the Scandinavian countries and the United Kingdom, the common board is made of forest thinnings, peeler cores, shavings and other mill waste. Most of the binder is urea with some urea-melamine mixtures being used. About 5% of the board is phenolic bonded. Properties of these boards do not include a linear expansion under extreme exposure conditions [19]. Specifications in the U.K. call for limits in expansion caused by a change of relative humidity from 65 to 90% (0.35% maximum linear expansion) [7]. This standard covers "chipboard" of small particles; it does not include waferboard or flakeboard. These products would be expected to have less linear expansion than chipboard. It is claimed that maximum expansion does not occur in floors and that the restraint in linear expansion caused by nailing the panels to joists prevents any significant buckling or other problems [8]:

> It is recommended that a slight gap between boards to accommodate some swelling and adequate ventilation of the roof void should be incorporated in the construction.

The technical manual, *Wood Chipboard 1977*, in referring to flat roof deck (which must be of flooring grade chipboard), states that the deck must have a "...3 mm (1/8 in.) expansion gap between boards and 12 mm (1/2 in.) where boards butt against an upstand" [11].

Where appropriate, blocking must be used to support panel edges; alternatively, panels can be tongue and groove on edges. Morkved [21] discusses the extensive use of particleboard flooring in Norway over the past 10 years. He shows a tongue and groove joist designed to have a gap in the bottom of the groove and a gap in the lower lip. The top lip is tightly butted together. Long periods of exposure to rain show some swelling in the joints, but the panels essentially recover their original thickness after drying.

WSU Field Survey Observations

The most important observation consistent with previous experience was that expansion gaps between panels as specified simply were not provided in virtually all cases. Some problems consequently occur, as in the case of a builder of a large, flat-roofed commercial building (about 200 ft wide). He claimed that the roof had expanded about 3 in. and had pushed a

parapet wall out of line. The expansion was perpendicular to 2 by 12 in. joists, and the bridging was not nailed. This would be an expansion of about 0.125%. He had to remove the wall, cut off the sheathing and then replace the wall. He said that he would now space the roof sheathing up to 1/4 in. in the winter but that it was not necessary to do so in the summer.

Such expansion does take place, but it is normally not observed because the ends of the roof or deck are not usually boxed in with a masonry wall as in the case above. Rather, the expansion comes and goes without being observed.

Western Washington. A year-round building schedule including all phases of framing and finishing is followed at all times. The general feeling is that weather interferes only about 5 days per year. Most of the time, workmen wear rain gear and work through the rain. Sheet materials and lumber are generally unloaded at the job site without regard to weather; most often no attempt is made to cover anything to keep it dry. Floor and roof sheathing are nailed on and exposed to the weather for whatever length of time is necessary to put the roof on. In some cases, this is a matter of a few days; in others, as in that of one large church, the plywood on a flat surface was exposed for two months.

Plywood is by far the most common roof sheathing. The most commonly used thickness is 1/2 in., followed by 5/8 in. A number of buildings with shake roofs use 1 by 4 in. and 1 by 6 in. spaced lumber sheathing.

The majority of walls are sheathed with 1/2 in. plywood. Some fiberboard is being used, with plywood at the corners. A product called Thermo-Ply® , manufactured by the Simplex Company, is also being used for wall sheathing without shear bracing. This product is 1/8 in. pressed cardboard with aluminum foil facing on both sides.

The general consensus is not to use any type of structural particleboard. Past experiences with particleboard in wet conditions were all bad. This experience could have been with underlayment in bathrooms. Some shavings type board is being sold in the Tacoma, Washington area for use as single-layer floor systems. Care is taken to be sure this board stays dry. Both 3/4 in. and 1 in. boards are being used. The main objection is the weight of the panel.

In the Vancouver, Washington area, the predominant subfloor over crawlspace areas is 2 by 6 in. T&G lumber installed over beams on 4 ft. centers. This is used instead of plywood. Particleboard underlayment is used to cover the subfloor. On upper floors, 3/4 in. plywood is used as subfloor. In some cases, it is glued to the joists with builders' adhesive although workmanship at times is poor, *e.g.*, adhesive is not applied to some joists.

In terms of coping with panels that have higher levels of linear expansion, the feeling is that any material must be as good or better than plywood and, if it is, maybe builders will use it if it will save money. At the present time, plywood serves very well. For the most part, plywood is used in all kinds of weather conditions, and no attempt is made to protect it from becoming thoroughly wet from the top side. After the building is under cover, the subfloor panels usually have some time to dry before underlayment is applied.

In the case of a builder of modular homes, where all building is done in the open, butane heaters are used to dry everything out after a house is enclosed.

Plywood is not spaced when applied unless a crack develops due to poor alignment. One builder said that he had some problems with linear expansion and that during the winter he did space plywood. Another builder claimed that one of his best jobs was done by applying wet plywood. When it dried, automatic spacing was achieved. For the most part, whatever spacing of roof sheathing found was due to poor

workmanship. Builders find it difficult to provide spacing at the ends of the panels because they are 8 ft. long, making it impossible to space the sheathing and keep the ends on trusses or rafters spaced 16 or 24 in. on center.

One builder had used some composite panel material but had poor results because of expansion. He also had strict requirements about what plywood to use. He had some plywood subflooring that had been exposed to the weather for 2 months which was still in good condition in most places.

The type of building material used is primarily controlled by the builder, although designers put requirements on plans to satisfy building codes. The builder may or may not follow the designer's recommendations. In fact, some builders who have been in the business for years are very reluctant to follow design recommendations. In some cases this has led to very costly rebuilding, especially on special applications where proper fastening was important.

The general opinion of designers is that changes in building practice are usually initiated by small construction companies who may be more interested in small cost savings. Larger construction companies like to keep doing what has worked well in the past; they will not use a new product until it has been proven to their satisfaction.

A large forest products company involved in producing prefabricated building parts has considered leaving the business because of the poor workmanship of subcontractors. Evidently, the company does not want to be held responsible for poor quality of construction.

Most builders felt that better quality plywood (fewer voids) would help them do a better job. A lower cost building material would be considered, but it would have to be as good as plywood.

Louisiana. The homes and apartments under construction which were visited had concrete slab floors and wood frame construction. Many were to have brick veneer as the exterior wall finish. The roof sheathing was 1/2 in. plywood with 3/4 in. plywood for the subfloor in the upper floor (in multistory buildings). Most wall sheathing was some type of insulation panel (polyurethane, styrofoam, or the Thermo-Ply® panels described previously). Some used plywood at the corners and midway on the wall for developing racking strength. The builders were energy conscious, stressing conservation. They were selling the extra insulation being applied as a feature, and some were building with 6 in. thick walls to allow for more insulation. Some expressed surprise that, even with the oil shortage, so much oil-based material (foam) was being used in building. They felt it would be more sensible to use fiberglass or mineral wool.

The plywood was CDX interior type of plywood with exterior glue. No one was allowing for gaps between panels even when they were clearly stamped with the instructions. Some buckling was observed on one roof of a newly finished, relatively large duplex. However, the builder stated this was not a problem in selling the house.

Builders are interested in other panels but only if they are lower in cost. They stated they would use a lower cost panel even if the quality were lower. They prefer 1/2 in. or thicker plywood as they dislike the springy feeling of 3/8 in. plywood when it is walked upon. They commented that blisters in the panels gave them more problems than core voids. Concern was expressed about the weight of any panel when they had to be handled in awkward situations. Also, problems were found when cutting any panel containing glue. This probably was due more to low quality sawblades than anything else.

At the present time, houses are being built and sold quickly to save on interest charges. This was inadvertently beneficial to the wood products since they are exposed to bad

weather for a much shorter period. The panels and lumber used in buildings constructed at a leisurely pace were more apt to have received considerable rainfall.

Large, low-rise buildings were made with steel trusses and folded metal-plate roof panels in this area. This seems to be a promising market area for wooden trusses, Trus-Joists®, or wooden I-beams and plywood or composite panel sheathing.

Missouri and Ohio. Surveys were conducted in Kansas City and Independence, Missouri; and in Cincinnati, Dayton, Brookville, and Columbus, Ohio. Builders of low-cost tract houses, builders of custom-built homes, apartment house builders, and builders of retirement centers were among those contacted. In all of these areas, plywood is the standard panel material being used. It is being used without spacing except where 3/8 in. plywood is being utilized with clips for roof sheathing. In this case, the clips provide spacing between the edges of panels. The exception of the "plywood only" sheathing rule is in the Columbus, Ohio area, were some 7/16 in. waferboard is being used to replace 3/8 in. plywood. The waferboard is being installed without spacing. Comments of the builders are that the waferboard feels stiffer than the plywood it is replacing. No buckling problems have been noted by the builders.

In general, plywood is not used for wall must not be left to the mercy of the ly from sheet to sheet. COM-PLY®, because bracing. The common plywood found in the area is southern yellow pine with 5/8 in. thick plywood being used for subflooring and 1/2 in. plywood for roof sheathing. A large portion of the plywood being used on floors is T&G. This has led to one of the major complaints of builders: some of the time the overall width of the T&G plywood, including the tongue and groove, is 4 feet, which leaves the net width of the plywood at 47½ inches. Some manufacturers, however, do make T&G plywood with a net width of 4 feet. The complaint comes when a supplier provides a builder with both widths of plywood for the same job. Other major complaints voiced against plywood panel materials were largely concerned with the quality of the panels. Complaints included out-of-square panels, delamination of face plies, buckling of individual face plies over delaminated core areas, and voids in the cores.

Builders in these areas do not stop building when it rains. They do stop building in winter because of heavy snow and cold weather. Builders try to cover their buildings as quickly as possible but do not worry about sheathing materials getting wet in rainstorms.

The most important observation of the WSU research was that, as far as the builders were concerned, spacing of panels was definitely out of the question. Building is very time-competitive, and spacing takes time.

Methods of building varied from place to place; however, most of the building was being done by subcontractors. There were no union carpenters doing this type of building.

Pullman, Washington. Numerous small contracting companies operate in this area. At present, no large tract builders are involved because the rapid expansion of housing has slowed, although there have been several large commercial buildings erected using Trus-Joist® or similar roof framing members and plywood sheathing.

This area has a climate in which the equilibrium moisture content of wood in buildings stays at about 6% year round. Thus, some of the severe moisture ranges found elsewhere in the country are not a factor in building in this area. The rainfall is about 25 in. per year, so the chances of extensive exposure of the wood during the construction period also is not as severe as elsewhere in the country. With reasonable speed in construction, buildings need not be

exposed to weather for long; however, many long exposures have been noted over the years.

Spacing panels according to specifications is apparently rarely practiced. One builder noted that he had heard of the spacing requirements but did not know what they were. No particular problems were being found without spacing; therefore, builders are not concerned with the specifications.

The "Conservation House"

The "Conservation House" was designed and built for maximum energy conservation in both heating and cooling seasons. The house was constructed for private owners in Brookville, Ohio in 1978-79 by J. W. Talbott (co-principal investigator). Heating and cooling data will be monitored over the next several years.

COM-PLY® composites made with oriented-flake cores were used throughout the house for wood basement walls, wood basement floors, wall sheathing, floor decking, roof sheathing, and ceilings. Table 18 provides data on the various uses of the composites, their applications, and exposure to the elements when under construction.

All panels were laid tight without any expansion gaps either at ends or at edges. No buckling or other distress was observed at any time. About 1/4 to 3/8 in. upward bowing of stressed-skin systems was observed when the deck was rain-soaked; however, the floor returned to its original level when dry.

When the house was occupied, all applications utilizing the composite panel were satisfactory to the builder and owner.

Literature and Survey Conclusions

Surveys in the U.S. showed that panels are not being applied with gaps between them, particularly roof sheathing. Most builders contacted were not aware of spacing requirements or at least did not admit that they had any such knowledge. Plywood, for the most part, has successfully been "misapplied" by eliminating gaps between panels without particular complaints from users. Thus, any competitive panel material would seemingly be forced to stand up to the same type of abuse as plywood.

When floors or roofs of structural panels are boxed in with a rigid wall, such as found with masonry, excessive exposure to moisture can cause enough panel expansion to move the rigid wall. In most cases, however, the linear expansion that does take place in the field is unnoticed.

Particleboard experience in the U.S., Canada, Australia, New Zealand, and western Europe shows successful structural uses of a variety of particleboards. These boards are bonded with highly moisture resistant phenolic resins, urea resins with much lower moisture resistance, as well as several combinations of resins and isocyanates. No one reports failure in using these panels, although some problems have undoubtedly occurred. Similar complaints about plywood have also been made over the years. The main point is that well-made, correctly used panel materials are serving well throughout the portion of the world discussed. Indeed, even when applied contrary to specifications or recommendations, most of the panel materials function properly.

All panel types discussed are usually not exposed directly to the weather, and indications are that only hardboard, plywood, composites, and cement-bonded particleboards can stand up to direct weather exposure at present. On the other hand, when protected, all panels apparently successfully resist degradation except when a situation develops in which improper building practices result in continuous dampness.

Nevertheless, we do not want to belittle the need for better stability, particularly for those applications requiring maximum stability, such as stressed-skin panels and siding applications.

Table 18. Composite application and exposure to the weather in the conservation house.

	Application		
	Name	Construction details	Weather exposure
1.	Outer basement wall cladding	Treated 1/2 in. composite, staple-glued (resorcinol) to 2 by 6 studs 16 in. on center (oc). This was a two skin stressed-skin panel with the inside composite making up the second skin.	Exposed to several days rain before covering with asphalt and 6 mil polyethylene film.
2.	Inside basement wall cladding	See No. 1. Inside skin was 1/2 in. staple-glued (casein) to 2 by 6 studs.	Stayed dry.
3.	Basement floor	Untreated 5/8 in. tongue and groove panels staple-glued (casein) to 2 by 4 joists 16 in. oc.	Stayed dry.
4.	Floor deck	Untreated 5/8 in. tongue and groove panels staple-glued (casein) to 2 by 6 joists 16 in. oc. This was also a stressed-skin system with the basement ceiling forming a second skin. The tongue and groove joint was also glued.	Received 3 in. of rain in 2 weeks. Total deck swelled 1/2 in. longitudinally (0.0087%). Bottom of deck stayed mostly dry.
5.	Basement ceiling	Untreated 1/2 in. panels staple/glued (casein) to 2 by 6 joists. Unsupported joints splice-plated with glued splice plates of the composite.	Stayed dry.
6.	Wall sheathing	Untreated 1/2 in. panels stapled to 2 by 6 studs 24 in. oc.	Exposed to 4 weeks weather including 4 in. of rain.
7.	Roof sheathing	Untreated 5/8 in. tongue and groove panels stapled to trusses 48 in. oc.	Top face saturated with dew for 4 nights (eaves were dripping in the mornings). Face checking occurred when dried during the day.

PHASE 2 GENERAL DISCUSSION

It is known that the common CDX plywood used for sheathing purposes works without buckling when it is well fastened down. This occurs even when it is applied without proper spacing and when exposed to liquid water from one side. It is also known that the composite panel using randomly formed shavings-type furnish and bonded with an isocyanate binder works without buckling when exposed to water on one side as long as it is well fastened down and proper spacing is used around the panel perimeter.

While spacing between panels appears to be a practice, it may not necessarily always be appropriate. It is already known that plywood, for the most part, has been functioning without perimeter gaps. The linear expansion evaluation of the representative plywood, composite and particleboard panels provides excellent data for examination.

The linear expansions for many of the panels evaluated in this Phase 2 research in the unrestrained condition would appear at first to be so excessive that they could not be used in building. The fact remains, however, that they are used successfully. The actual wetting in field conditions takes place slowly from one side as the panels are wetted from the top side down. Expansion is being restrained by the nails—proper nailing is extremely important and cannot be overemphasized—and by the lower layers of the board that are not wetted. As shown by Kasper and Carroll [17], this reduction in expansion from the unrestrained state is tremendous. They show that 62% of the expansion is absorbed internally without panel buckling. In the case of the composite with random core, the linear expansion in the across-panel direction would be reduced from 1.5% in free expansion to 0.57% in restrained expansion, if the Kasper and Carroll conditions, when going from 30% RH to soak, apply.

Table 19 presents the actual linear expansion that would occur in full-size panels of the type evaluated when going from 30% RH to soak. These values are compared to specified gaps to be left between panels used or roof sheathing. The plywood products would expand to close the gap. The expansion of the composite with aligned core greatly exceeds the gap specification in the 4 ft. panel direction, as does the composite with random core. Waferboard would not expand more than the specification across the width, but exceeds the length specification. The particleboards have greater expansions than the plywood products, but all would exceed the 0.060 in. gap spacing specified by ICBO for Redex Particleboard [15]. However, all panels work in practice. More needs to be learned about misuse and field problems. The important point is that they do work as far as linear expansion is concerned because the nailing practices and the one-side wetting found in actual construction are the factors governing whether or not the panels function properly.

Research at the American Plywood Association is showing that plywood can buckle spectacularly when applied so that the unsupported length is very long in relation to its thickness and bending stiffness. Such buckling occurs under one-side water exposure such as found with ponding of water on a subfloor system. Further research is needed to develop a clear understanding of the relationship of linear expansion to buckling for all types of structural panels under restraint when wetted on one side.

Composite products will have to fit into the American structural plywood market and be applied in the same manner as plywood, which includes no spacing between panels, particularly on roofs. The panels will have to function without buckling. If spacing is required, whether it is for composite products or any other type of structural panel, buckling will have to be

Table 19. Cumulative unrestrained linear expansion (in inches) in full-size panels from exposure at 30% relative humidity to soak compared to specifed spacings (in inches) between panels.

Study No. and Name	4 ft direction	8 ft direction	Specified Gap End	Edge
1. Urea flakeboard (Australia)	0.33	0.51	--	--
2. Urea flakeboard (U.K.)	0.37	0.62	--	--
3. Urea flakeboard (N.Z.)	0.21	0.35	--	--
4. Melamine-urea flakeboard	0.24	0.39	--	--
5. Melamine-phenol flakeboard	0.20	0.34	--	--
6. Phenolic flakeboard	0.20	0.38	--	--
7. Waferboard	0.13	0.21	0.13	0.13
8. Radiata tannin flakeboard	0.27	0.45	--	--
9. Wattle flakeboard	0.23	0.40	--	--
12. Composite, aligned core (phenol)	10.16	0.07	0.06	0.13
13. Composite with random core (isocyanate)	0.72	0.07	0.06	0.13
14. Plywood, 4-ply, CDX, Douglas-fir	0.06	0.08	0.06	0.13
16. Plywood, 4-ply, CDX, Southern pine	0.04	0.07	0.06	0.13

avoided by building into the system some method of providing spacing around the perimeter of the panels automatically. This must not be left to the mercy of the workmen on the site.

J. W. Talbott's experience using flakeboard for structural purposes shows that the product can be used as a combination exterior siding/sheathing on studs 24 in. on center without buckling. In this particular application, the product was well wetted by rain before painting.

From the previously mentioned Potlatch experience, and from Talbott's recent experience in constructing an experimental home in Ohio using a composite, it is known that a COM-PLY® product with oriented flake cores can be used in both nailed sheathing and glued stressed-skin applications without buckling or other distress when exposed to water on one side. In fact, basement stressed-skin panels have remained straight. This is a preservative-treated wood basement system. Also, stressed-skin floor systems (5/8 in. T&G composite on 2 by 6 in. joists spaced 16 in. on center) only bowed up 1/4 in. on a 14 ft. span after a cumulative rainfall of 3 in.

Linear expansion of plywood varies greatly from sheet to sheet. COM-PLY® , because of its greater uniformity in linear expansion contributed by its uniform particleboard core, might have a higher mean linear expansion and yet encounter no more buckling problems than plywood. The linear expansion variation in plywood can be seen in the measurements presented in Table 16 on the southern yellow pine CDX plywood evaluated. Some panels had four times the linear expansion of others due to the presence of compression wood in one or more layers.

Laboratory measurement of linear expansion after humidity exposure or water soaking probably is useful as a quality control test; however, these measurements should be combined with EI and unsupported panel

length in applications to predict buckling performance. Coating or sizing of panels may be very useful in minimizng buckling by retarding liquid water pickup. As noted previously, however, such coatings have not been found to be particularly advantageous with particleboard in other parts of the world.

In stressed-skin panels, bowing from seasonal moisture changes is usually more important than buckling or bowing from liquid water uptake. In this case, the laboratory linear expansion values are of more direct value. Higher degrees of stability are also very desirable. Thus, the greater the span/depth ratio of the panel, and the greater the contribution of the skin to EI, the more important is the dimensional stability of the skin.

Composites with oriented-flake cores and composites with random particle cores were both as stable as plywood in the direction parallel to the face grain. This implies that the stability in the direction perpendicular to the face plies will be the most critical in all COM-PLY® products. The further implication is that orientation will be important for stability. Orientation improves the LE of the core in the critical direction and enhances E in the critical direction, which enables the core to better resist the expansion of the faces. This increases the EI of the COM-PLY® in the cross direction where it is most vulnerable to buckling. Orientation also improves mechanical performance of the panel.

It is fortunate that the same factors in COM-PLY® cores—such as favorable particle geometry and particle alignment—which contribute to dimensional stability of the composite panel, also enhance the cross-panel tensile and compressive strength and stiffness necessary to many stressed-skin applications. Thus, such improvements work together to increase the general utility of structural panels for both conventional and newer, more sophisticated applications.

CONCLUSIONS—PHASE 2

Establishing limits for linear expansion based on this research is extremely difficult and will require a combination of predicting equations including the ones reported herein, and others which need to be developed relating buckling to fastener spacing, slenderness ratios, and the one-side wetting that occurs in actual use. There will be a hierarchy of values for different end-uses. Some will tolerate more linear expansion than others. The important point is that there probably will not be one fixed answer.

The desirable panel layups for COM-PLY® will be governed by decisions for developing both stability and mechanical properties and the end-uses that the panel will meet.

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1981 Linear expansion design theory for COM-PLY panels. USDA For. Serv., Res. Pap. SE-224, COM-PLY Rep. 21, 56 p. Southeast. For. Exp. Sta., Asheville, N.C., and U.S. Dep. Housing and Urban Develop., Washington, D.C.

A theory was developed for predicting linear expansion of COM-PLY panels with increasing panel moisture content. Equations are presented to predict panel expansion when the component materials behave elastically at low moisture contents and inelastically at high moisture contents. The strength and stiffness of a variety of veneer and particleboard components were measured to develop linear expansion equations. The results show it is possible to make COM-PLY panels with linear expansions that range from acceptable to totally unacceptable for residential construction.

KEYWORDS: Plywood, panel swelling, composite panels, dimensional stability.

Talbott, John W., Thomas M. Maloney, F. Max Heffaker, Robert J. Hoyle, Jr., and Robert W. Meyer
1981 Linear expansion design theory for COM-PLY panels. USDA For. Serv., Res. Pap. SE-224, COM-PLY Rep. 21, 56 p. Southeast. For. Exp. Sta., Asheville, N.C., and U.S. Dep. Housing and Urban Develop., Washington, D.C.

A theory was developed for predicting linear expansion of COM-PLY panels with increasing panel moisture content. Equations are presented to predict panel expansion when the component materials behave elastically at low moisture contents and inelastically at high moisture contents. The strength and stiffness of a variety of veneer and particleboard components were measured to develop linear expansion equations. The results show it is possible to make COM-PLY panels with linear expansions that range from acceptable to totally unacceptable for residential construction.

KEYWORDS: Plywood, panel swelling, composite panels, dimensional stability.

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Research Paper SE-225

Resistance of COM-PLY Lumber to Subterranean Termites

COM-PLY 22
REPORT

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Southeastern Forest Experiment Station
Asheville, North Carolina

Resistance of COM-PLY Lumber to Subterranean Termites

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Cooperative Research by
U.S. Department of Agriculture, Forest Service
Southeastern Forest Experiment Station
Southern Forest Experiment Station
and
U.S. Department of Housing and Urban Development
Division of Energy, Building Technology and Standards

PREFACE

This report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in houses. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem and that long-range plans for better use of the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with particleboard and veneer as a way of using not only more of the tree stem but also using less desirable trees and a greater variety of tree species than would conventional wood products. The particleboard, which forms a large portion of COM-PLY studs and joists, is made from chipped wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Georgia. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, preservative treatment, termite resistance, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid-wood lumber, suggest performance standards for composite lumber, and provide construction details for incorporating such lumber in houses. Still others will explore the economic feasibility of manufacturing composite lumber and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

Resistance of COM-PLY Lumber to Subterranean Termites

Abstract. In two types of no-choice laboratory tests, untreated COM-PLY material was less susceptible to termite attack than was untreated sawn southern pine. Lower termite survival on COM-PLY specimens was attributed to residual resin binder components in COM-PLY acting as termite deterrents.

Keywords: Termites, composite lumber, particleboard, laminates.

INTRODUCTION

Resistance to or protection from subterranean termite attack is desirable in any construction lumber, but it is particularly important in joists because of the loads they must bear. The study described here was designed to compare termite resistance of COM-PLY lumber with that of conventionally sawn southern pine sapwood lumber. The hope was that the COM-PLY would be at least as resistant as the material it was designed to replace. Results presented here indicate that certain properties of the particleboard and of the phenol resorcinol formaldehyde adhesive used to bond veneer to the particleboard made the COM-PLY less favorable than conventional southern pine lumber for termite feeding.

TEST MATERIALS

Three-layer southern pine particleboard consisting of two outer layers of compacted small particles (specific gravity 0.72) and a less dense inner layer of larger particles (specific gravity 0.57) was tested. It was obtained from two sources: Washington State University (WS) and the Georgia–Pacific Corporation (GP). WS boards were prepared from ring-flaked pine boards and were stored in a ventilated laboratory conditioning room in Athens for at least 18 months. GP boards were prepared from ring-flaked plywood residue. Separate samples of GP boards were exposed to one of three conditioning environments: (a) solid-stacked with little or no ventilation for more than 1 year, (b) weathered outdoors for 6 months, and (c) steamed in a laboratory autoclave for 30 minutes. Resin chemical losses should have been greater in boards conditioned under environments b and c than under environment a.

At the Athens laboratory, joists (nominal 2 by 8 inches or 5 by 20 cm) were fabricated with GP and WS particleboard. Four southern pine veneer layers, each 0.25 inch (0.9 cm) thick, were first laminated into 1-inch (2.5 cm) units and then bonded to each edge of the particleboard. The veneer was bonded with phenol–resorcinol formaldehyde (PRF) adhesive in a cold press.

For bioassays, pairs of blocks were cut from selected locations in selected test material (fig. 1). Table 1 lists sampling locations and storage conditions for test blocks. All blocks measured 2 cm square by 1 cm thick (about 0.8 inch square by 0.4 inch thick). In each test, types of blocks were replicated 10 times. Control blocks were cut from defect-free southern pine sapwood with about six rings per inch. Each block was weighed before it was tested, and an initial ovendried weight was calculated on the basis of the moisture content of matched blocks.

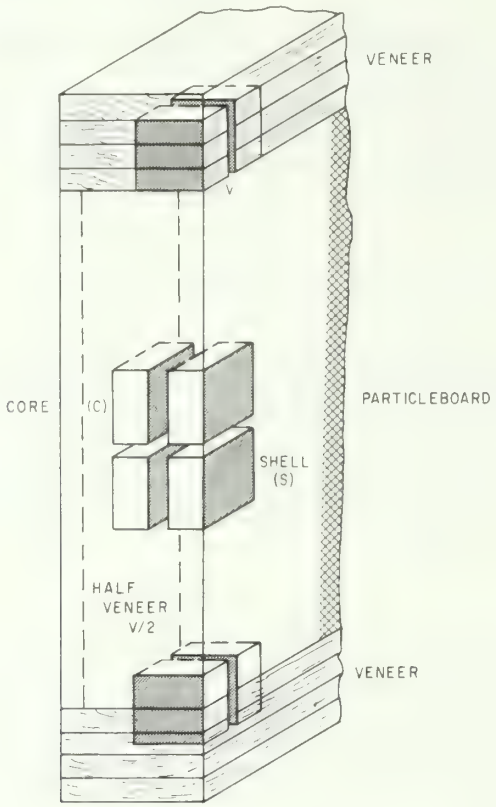

Figure 1.—Location of test blocks in the cross section of COM-PLY lumber. Shaded areas indicate the surfaces to be in contact with sand in the Gulfport test.

Table 1.—Test material description

Code	COM-PLY particleboard		Block location
	Source	Condition	
WS-S	WS	Ventilated	Shell
WS-C	WS	Ventilated	Core
GP-S	GP	Stacked	Shell
GP-C	GP	Stacked	Core
GP-V	GP	Stacked	Veneer
GP-V/2	GP	Stacked	1/2 veneer, 1/2 particleboard
GP-W	GP	Weathered	Shell
GP-St	GP	Steamed	Shell
Control			Sawn southern pine sapwood

WS=particleboard prepared by Washington State University.
GP=particleboard prepared by Georgia-Pacific Corporation.

One large colony of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), was collected from a southern pine log in southern Mississippi. Sections of the colonized log were placed in 75-liter galvanized cans and kept under laboratory conditions until termites were needed. Termites were taken from this colony on the day that the tests were established.

TEST METHODS

Matched pairs of blocks were split between two standard forced-feeding or no-choice exposure tests. In tests developed at Gulfport, Mississippi (Smythe and Carter 1969), plastic test containers 5.0 cm in diameter and 3.5 cm high were filled with 50 g of autoclaved sand and moistened with 7 ml of distilled water to maintain a high humidity. A weighed test block was placed on top of the sand, and 100 "worker" termites (externally undifferentiated termites beyond the third instar) were added to each container. Test containers were kept in an environmental chamber at 25° to 26° C for 8 weeks. At weekly intervals, living termites were counted and their condition recorded. After 8 weeks, test blocks were ovendried and weighed to estimate the amount of wood eaten (calculated initial ovendried weight–final ovendried weight).

In an ASTM (1976) test, the weighed test block was placed at the side and bottom of an 8-ounce glass container and covered with 200 g of sand, which was moistened with distilled water. To each container was added 1 g of termites (400 to 500 termites including all castes present in the colony). The test containers were maintained for 4 weeks at 25° to 26° C. Survival was estimated from the ratio of the final weight of test termites to the initial weight. Test blocks were also ovendried and weighed to estimate wood eaten.

Test blocks were examined for termite damage and rated according to the ASTM standard (1976) and according to a method used at the Gulfport laboratory (Beal and others 1974). Ratings were: 0 = no damage; 1 = slight damage, surface nibbling; 2 = medium damage; and 3 = heavy damage, deep penetration.

Data for survival (percent) and block weight loss (mg) were subjected to one-way analysis of variance. For each response, differences in treatment means were compared at the 0.05 level by Duncan's new multiple range test.

Additional tests were run on veneer samples bonded with phenol–resorcinol–formaldehyde adhesive that were conditioned as follows: (a) stacked with little or no ventilation, (b) weathered outdoors for 6 months, and (c) ovendried at 100° C for 48 hours. Ten replicates of each treatment and control (sawn southern pine sapwood) were exposed for 4 weeks by the Gulfport bioassay described above.

Similar tests were done on veneer freshly fabricated (cold-pressed) using phenol–resorcinol–formaldehyde, polyvinyl acetate, and isocyanate adhesives. Control blocks consisted of veneer wood (no glue line) held together as a block with a rubber band. Three replicates of each test material were exposed for 4 weeks by the Gulfport bioassay.

RESULTS

Gulfport test.—Average survival was 10 percent on all COM-PLY blocks and 73 percent on the pine sapwood control blocks. For COM-PLY blocks, the highest survival was 33 percent of the termites on blocks from the shell layer of GP particleboard which had been weathered outdoors for 6 months (GP-W). No termites survived on blocks containing one or more glue lines; i.e., blocks consisting of all veneer (GP-V) or half veneer (GP-V/2). Also, no survival occurred on blocks from the shell layer of GP particleboard (GP-S).

Termite survival (percent) and block weight loss (mg) were closely correlated (table 2). The control blocks had the greatest mean weight loss, 428 mg, which was significantly greater than the weight loss of any COM-PLY material. The overall average weight loss for all COM-PLY blocks was 143 mg, about one-third of the loss for the pine control blocks. COM-PLY blocks containing glue lines (GP-V and GP-V/2) showed no weight loss. Of the COM-PLY materials, greatest weight loss was obtained with blocks made from WS particleboard (WS-S and WS-C) and from weathered GP particleboard (GP-W). Weight loss was not significantly different for these three materials, but was significantly greater than that of the remaining COM-PLY samples and lower than that of the control blocks.

ASTM test.—As in the Gulfport test, termite survival on the pine sapwood control blocks in the ASTM test was significantly higher than survival on any COM-PLY material (table 2). On the control blocks, 86 percent of the termites survived at 4 weeks, whereas mean survival on all COM-PLY blocks was 48 percent. The shorter test period of 4 weeks accounts for overall higher survival in the ASTM test (table 2). However, as in the Gulfport test, no termites survived on the all-veneer (GP-V) blocks, and only 12 percent of the termites survived on half-veneer (GP-V/2) blocks. For the COM-PLY blocks, highest termite survival occurred on blocks cut from the WS source (69 percent on the WS-S and 71 percent on WS-C).

Table 2.—Termite survival and block weight loss in 4-week ASTM and 8-week Gulfport no-choice tests on COM-PLY materials

Material	Termite survival		Block weight loss	
	ASTM	Gulfport	ASTM	Gulfport
	Percent		*mg*	
GP-V	0a	0a	73a	0a
GP-V/2	12b	0a	148b	0a
GP-S	53c	0a	482c	40b
GP-C	65de	4a	644d	85b
GP-St	56c	6ab	508c	168c
WS-S	69e	16bc	713e	239d
WS-C	71e	22c	775f	300d
GP-W	61cd	33d	583d	309d
Control	86f	73e	807f	428e

Means in a column followed by the same letter are not significantly different at the 0.05 level as determined by Duncan's new multiple range test.

Values shown are means of 10 replicates with 100 termites on the Gulfport and 1 g of termites on the ASTM tests initially per replicate.

Weight loss of the pine sapwood control blocks (807 mg) was not significantly different from that (775 mg) of WS particleboard core blocks (WS-C), but was significantly higher than that of all other COM-PLY blocks (table 2). The all-veneer (GP-V) and half-veneer (GP-V/2) blocks had the lowest weight losses, as one would expect from termite mortality data. The greater weight loss of blocks in the ASTM test than in the Gulfport test resulted from the large initial numbers of termites per test container in the ASTM test.

Visual damage rating.—Visual damage was not as severe in COM-PLY as in pine sapwood blocks. All control blocks in both tests showed heavy damage and great penetration by the termites (3 rating). Termites tunneled through the soft springwood bands of the control blocks, very often from one block face to the opposite face. Gulfport test blocks consisting of all veneer or half veneer were generally rated 0, and most shell and core blocks from stacked GP particleboard (GP-S and GP-C) were rated 0 or 1. Of the COM-PLY samples, WS-C, GP-W, and WS-S blocks showed the greatest damage; many of these blocks were rated 3. Ratings correlated well with the block weight losses in mg. On matched COM-PLY blocks, damage was more severe in the ASTM test than in the Gulfport test, and the ratings were correspondingly higher. The greater number of termites in the ASTM test and the burial of the block under moist sand may have contributed to heavier damage. However, visual damage in the ASTM test was still least on blocks containing veneer, as in the Gulfport test.

Glue-line effects.—In follow-up testing of veneer materials that had been exposed to different conditioning treatments, neither weathering for 6 months nor ovendrying at 100° for 48 hours reduced the effect of phenol-resorcinol formaldehyde glue lines on termite survival. No termites survived 2 weeks in any test container with veneer material. Termites were dead in all 10 replicates of the nonventilated veneer within 4 days, in 8 replicates of the ovendried veneer within 8 days, and in 9 replicates of the weathered veneer within 8 days. Termite survival on the control pine sapwood blocks averaged 88 percent at 4 weeks when the test was terminated.

In the tests with veneer prepared with different adhesives, no termites survived 4 weeks of exposure to blocks with phenol resorcinol formaldehyde or polyvinyl acetate. Termites died in less than 1 week on phenol-resorcinol-formaldehyde samples and in about 3 weeks on the polyvinyl acetate samples. Termite survival on the isocyanate blocks was high (79 percent) and similar to that (77 percent) observed on the veneer with no adhesive.

DISCUSSION

In laboratory no-choice tests, low weight loss, minimal visual damage of the test material, and low termite survival indicate resistance to termites. Results from both bioassays indicate that the southern pine sapwood control blocks were significantly more susceptible to the eastern subterranean termite, *R. flavipes*, than were COM-PLY test materials as a whole. In the 8-week Gulfport test, 73 percent of the termites survived in tests with the control blocks, and weight loss of the controls averaged 428 mg. These values are in the same range as the 81-percent termite survival and 514-mg block weight loss observed in previous tests of susceptible sapwood blocks of slash pine exposed to *R. flavipes* (Carter and others 1979).

Differences in test results between southern pine sapwood and WS particleboard made from southern pine sapwood probably resulted from free residual formaldehyde or phenolic resin in the particleboard. Since most formaldehyde is released from particleboard during and soon after manufacture, its concentration may vary greatly between boards and even at various locations within a board. Although one would expect a greater release of formaldehyde from the shell layers of the particleboard than from the core, the density of the outer layers is considerably greater than that of the inner layer. Thus, one factor compensates for the other.

Particleboard sources or types could significantly affect termite resistance. In the Gulfport test, termite survival and block weight loss were significantly higher in WS than in GP particleboard. The latter was made from plywood residue, and the phenol formaldehyde resin used in the manufacture of plywood may have been an additional source of residual formaldehyde or phenolic resin in the GP particleboard. In Gulfport tests with blocks cut from the shell layer of GP particleboards that had been exposed to different environments, differences in results can most likely be attributed to differences in the concentrations of residual resin materials. Differences between these treatments were not as great in the ASTM test as in the Gulfport test, but the same trend was apparent.

All samples containing a glue line (GP-V and GP-V 2) severely reduced termite survival and were damaged least. In the follow-up tests, termites survived only slightly longer on the ovendried or weathered veneer material (about 8 days) than on the unventilated material (less than 4 days). Thus, the decrease in the concentration of the antitermitic material by these treatments was not sufficient to affect the overall test results. The action of this material as a fumigant on the termites was confirmed as follows. Three test containers, each with 50 termites on a moist absorbent paper pad, were placed on the surface of moist sand in a small crisper dish (about 17.5 by 12 by 6 cm). Ten veneer blocks were distributed on the wet sand surrounding the test containers which were left open to determine if vapors from the wood would kill the termites. The lid was placed on the crisper dish. Within a week most of the termites were dead or dying; the 16 still alive at 1 week were sluggish in their movements or were immobile and died within a few days.

The adverse effect on the termites of the phenol–resorcinol formaldehyde adhesive in the laboratory-prepared cold-pressed veneer may not occur from production veneer laminates, which are usually bonded with phenol–formaldehyde adhesive and hot-pressed. Therefore, additional studies should include comparisons of the two adhesives.

Additional studies should also be initiated to determine the types of economical combinations of wood species which would increase resistance to termite attack and utilize otherwise little-used species as well. Mixtures of termite-resistant wood and susceptible wood in particleboard have already been tested on a small scale (Behr 1972; Behr and Wittrup 1969). A particleboard (8 percent phenol-formaldehyde) made with 35 percent heartwood of northern white cedar and the remainder jack pine sapwood met ASTM standards for termite resistance. This combination was more resistant than combinations of redwood heartwood and jack pine sapwood. Certain southern hardwoods may also increase termite resistance (Carter 1976). Investigators of termites and termite damage have long noted that certain woods appear to have greater immunity to termite attack than do others. Factors determining attack of a wood sample by termites include quantity and chemical nature of the extractive components of the wood, moisture content, such physical qualities as density and hardness, relative amounts of springwood and summerwood, differences between heartwood and sapwood, and the nature and degree of pre-existing fungal attack. Of these factors, the chemical extractives are probably the most vital in determining the resistance to termite attack (Carter 1976).

Many factors can cause results of laboratory tests to differ from those obtained under use conditions. Often, various species of termites will respond differently to a test material. The subterranean termites used in this study normally colonize the soil and use it for moisture and nesting. Primary control of subterranean termites is by soil treatment with chemicals continuously scrutinized by agencies concerned with health and the environment. For termites that do not nest in the ground, soil treatment is not effective and other methods of protection should be used. In such cases, use of COM-PLY lumber with antitermitic properties would be valuable. Under certain conditions, COM-PLY lumber treated with antitermitic wood preservatives may be preferred. Results from recent studies indicate that preservative treatment of COM-PLY lumber has several advantages over similar treatment of solid pine (Gaby and Gjovik, report in preparation).

SUMMARY

Possible termite resistance of COM-PLY lumber was compared to that of conventional southern pine sapwood lumber in two no-choice exposure tests.

Major findings were:

- Southern pine sapwood lumber was more susceptible to termite attack than was COM-PLY material.
- Reduced termite survival and feeding on particleboard made with southern pine sapwood were attributed primarily to free formaldehyde or phenolic resin remaining in the particleboard.
- Termite responses varied by source of particleboard and environmental conditions under which the particleboard was stored before testing. The differences were attributed to variations in the residual concentration of phenol formaldehyde resin. Antitermitic properties of particleboard may vary greatly, because the residual concentration of the binding resin can be highly variable.
- A glue line greatly reduced termite survival and feeding in both tests. The antitermitic effect was attributed to the phenol resorcinol formaldehyde adhesive used to bond the veneer. Because these samples were prepared in the laboratory by a cold-pressed method, additional studies should compare cold-pressed laminates bonded with phenol resorcinol formaldehyde and hot-pressed laminates bonded with phenol–formaldehyde.
- Additional tests should include COM-PLY materials made with other wood species, especially species believed to be more termite resistant than southern pine sapwood. Various mixtures of antitermitic material with susceptible material should be tested for overall resistance to termite attack.
- As appropriate, additional tests should also include other species of termites.

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Gaby, Louis I., and Farrie Lyn Carter

1981 Resistance of COM-PLY lumber to subterranean termites. USDA For. Serv. Res. Pap. SE-225. COM-PLY Rep. 22. 6 p. Southeast. For. Exp. Stn., Asheville, N.C., and U.S. Dep. Housing and Urban Develop., Washington, D.C.

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Keywords: Termites, composite lumber, particleboard, laminates.

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Predicted Weights and Volumes of Firewood in Hardwood Trees in the Southeast

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Pounds per cubic foot	16.02	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor listed above.

April 1982
Southeastern Forest Experiment Station
Asheville, North Carolina

Predicted Weights and Volumes of Firewood in Hardwood Trees in the Southeast

by

Alexander Clark III, Wood Scientist
Utilization of Southern Timber
Athens, Georgia

Abstract.—Weights and volumes of firewood 4 inches d.o.b. or larger were determined for 247 hard hardwood and 257 soft hardwood trees from 5 to 28 inches d.b.h. growing in the Southeast. Equations are presented for predicting the green weight of wood and bark and volume of wood in firewood ⩾ 4 inches d.o.b. in the total tree above stump, in the main stem to 4-inch top, and in topwood above the saw-log top. Equations predict weight and volume of firewood using d.b.h. and total height, d.b.h. and height to 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Tables developed from equations show weight in pounds and volume in cords of firewood in a tree and its components by d.b.h. and height classes.

Keywords: moisture content, specific gravity, yield tables, biomass, equations.

Heating houses and small commercial buildings with wood is again a common practice in the South. Poor-quality hardwoods and topwood from sawtimber-size trees are now harvested for firewood. Equations and yield tables for estimating the weight and volume of firewood in a tree are needed to assist in the equitable marketing of trees for firewood.

To evaluate the timber resource in the Southeast, foresters have conducted studies to collect total-tree component biomass data on the commercially important hard hardwoods—northern red oak (*Quercus rubra* L.), southern red oak (*Q. falcata* Michx.), scarlet oak (*Q. coccinea* Muenchh.), chestnut oak (*Q. prinus* L.), white oak (*Q. alba* L.), water oak (*Q. nigra* L.), and mockernut hickory (*Carya tomentosa* (Poir.) Nutt.), and soft hardwoods—yellow-poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), blackgum (*Nyssa sylvatica* var. *biflora*), red maple (*Acer rubrum* L.), and white ash (*Fraxinus americana* L.) (Clark and others 1980, 1980a, 1980b; Clark and Schroeder 1977). In this paper the total-tree and component weight and volume data are used to develop equations for predicting green wood and bark weights and volumes for firewood 4 inches in diameter outside bark (d.o.b.) and larger in hard hardwood and soft hardwood trees growing in the Southeast. Equations and yield tables predict the weight and volume of firewood in the total tree above stump, in the main stem to 4-inch d.o.b. top, and in branches and stemwood above a saw-log top in sawtimber-size trees. The moisture content, specific gravity, and weight per cubic foot of firewood when harvested are also presented.

PROCEDURE

A total of 247 hard hardwood trees from 5 to 24 inches in diameter at breast height (d.b.h.) and 257 soft hardwood trees from 5 to 28 inches d.b.h. were sampled from various locations on five National Forests in the Southeast and in two counties in Tennessee (table 1). A stratified random sample of three to six trees per 2-inch d.b.h. class was selected at each location from uneven-aged, closed, mixed hardwood stands. Form class of the hard hardwood and soft hardwood sawtimber trees (trees ⩾ 11.0 inches d.b.h) averaged 79. The hard hardwood trees ranged from 27 to 160 years old and averaged 72 years, and the soft hardwood trees ranged from 21 to 108 and averaged 54 years old. Means and ranges in dimension of sample trees are shown in table 1 by species and location.

Trees were felled and limbed during the winter, and the main stem of each sawtimber-size tree was bucked into merchantable saw logs 8 to 16 feet long to a 9-inch d.o.b. top or where a Forest Service grade 3 log stopped. Stem diameter inside bark (d.i.b.) at the saw-log top averaged 11.4 inches in the hard hardwoods and 10.5 inches in the soft hardwoods. All material between the saw-log merchantable top and the 4-inch d.o.b. top was classified as stem firewood. All trees had a discernible main stem of a 4-inch top. The stem above the 4-inch top and branches were considered crown. In pulpwood-size trees (trees 5.0 to 10.9 inches) the main stem was bucked at 4-inch d.o.b. top. Crowns of the sample trees were cut up and weighed in two categories: (1) branches ⩾ 4.0 inches d.o.b. and (2) branches < 4.0 inches d.o.b. All crown material was

Table 1.--Means and ranges of tree measurements by species and location

Species	Location	Sample tree	D.b.h.		Total height		Height to 4-inch d.o.b. top		Height to saw-log merchantable top [1]		D.i.b. at saw-log merchantable top	
			Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
		Number	-- Inches --		---------- Feet ----------						-- Inches --	
					HARD HARDWOODS							
Northern red oak	Pisgah N.F., NC	71	13.0	5.9-24.7	84	53-118	60	18-98	50	25-78	9.9	7.4-15.0
Southern red oak	Coffee Co., TN	29	12.5	5.4-22.0	70	53- 84	45	13-65	24	18-35	12.4	8.6-16.9
Scarlet oak	Cumberland Co., TN	28	12.1	5.1-20.0	73	50- 94	48	17-69	29	13-45	12.5	9.1-15.1
Chestnut oak	Nantahala N.F., NC	24	13.1	5.6-20.9	82	47-115	61	18-94	46	28-66	11.0	8.5-14.0
White oak	Nantahala N.F., NC	28	13.9	5.1-21.7	84	38-110	60	9-85	46	34-64	12.0	8.4-18.0
White oak	Oconee N.F., GA	23	12.8	5.6-20.9	71	47- 93	47	20-71	33	18-43	11.8	8.3-15.6
Water oak	Francis Marion N.F.,SC	17	12.6	5.2-20.0	72	38- 92	51	19-77	31	26-40	12.1	9.4-16.5
Hickory	Chattahoochee N.F.,GA	27	12.5	5.1-19.4	82	48-108	62	20-91	43	17-59	11.4	9.1-14.3
All hard hardwoods		247	12.9	5.1-24.7	78	38-118	56	9-98	40	13-78	11.4	7.4-16.9
					SOFT HARDWOODS							
Yellow-poplar	Nantahala N.F., NC	26	14.1	5.6-22.4	95	51-128	70	20-104	66	28- 84	10.4	8.4-16.3
Yellow-poplar	Pisgah N.F., NC	39	13.9	5.8-28.4	99	53-147	72	13-129	67	34-102	9.5	8.0-15.2
Yellow-poplar	Oconee N.F., GA	26	13.5	5.5-20.3	84	58-107	62	21- 89	46	24- 67	10.1	8.0-14.5
Yellow-poplar	Francis Marion N.F.,SC	26	12.6	5.5-20.9	82	51-103	60	26- 85	46	27- 56	10.5	8.5-15.0
Sweetgum	Oconee N.F., GA	24	13.1	5.7-20.7	82	48-101	57	17- 81	42	20- 59	10.1	8.1-14.4
Sweetgum	Francis Marion N.F.,SC	23	14.1	5.1-20.0	85	55-108	65	25- 91	45	29- 71	11.4	8.6-15.5
Blackgum	Francis Marion N.F.,SC	32	11.5	5.4-19.5	74	49-101	54	15- 85	38	20- 56	11.3	7.7-14.5
Red maple	Nantahala and Pisgah N.F., NC	30	10.5	5.1-16.8	72	47-104	45	12- 80	27	18- 50	11.0	8.0- 4.9
White ash	Chattahoochee N.F., GA	31	10.8	5.0-18.6	77	44-119	56	15-103	37	17- 73	11.2	9.0-13.9
All soft hardwoods		257	12.6	5.0-28.4	84	44-147	60	12-129	48	17-102	10.5	7.7-16.3

[1] Height to 9-inch d.o.b. top or where Forest Service grade 3 log stopped.

weighed to the nearest one-quarter pound. Saw logs were weighed individually to the nearest pound.

From each sawtimber tree, disks were removed at the butt, at each saw-log bucking point, at the points where d.o.b. measured 9, 6, and 4 inches, and from branches randomly selected from each branch-size category. In pulpwood-size trees, disks were cut at the butt and at quarter points to a 4-inch top. Each disk was sealed in a polyethylene bag for subsequent determinations of moisture content, specific gravity, and bark percentage.

LABORATORY

Specific gravity was computed on a green volume and ovendry weight basis. Moisture content was computed on an ovendry weight basis after samples were dried to a constant weight at 215°F. Moisture content and specific gravity of stem and branches were calculated by weighting disk values in proportion to the volume of the component they represented.

Green weight per cubic foot of wood was calculated from weighted values for specific gravity and moisture content with the equation:

$$\text{Wood green weight per cubic foot} = \left[1 + \frac{\text{M.C.}}{100}\right] \times (\text{S.G.}) \times (\text{C}) \quad (1)$$

where: M.C. = weighted moisture content in percent,
S.G. = weighted specific gravity,
C = 62.4 pounds (weight of water per cubic foot).

Cubic-foot volume of green wood was computed by dividing component green wood weight by its green weight per cubic foot.

ANALYSIS

Linear regression equations were developed to predict the green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the total tree, in the stem to a 4-inch top, and in branches and stem above the saw-log top (topwood). Independent variables were: diameter at breast height (D), total height (Th), saw-log merchantable height (Mh), and height to a 4-inch top (H4), both separately and in various combinations.

Grouping the data into D^2Th and D^2 classes and plotting the variance of Y over D^2 and D^2Th indicated that the variances of predicted weights and volumes increased with increasing D^2 and D^2Th. The logarithmic transformation (to the base 10) was used to obtain a relative homogeneous variance, which is assumed in regression analysis. Thus, regression equations for estimating weights and volumes were calculated using the models:

$$\log Y = b_0 + b_1 \log X + \epsilon \quad (2)$$

$$\log Y = b_0 + b_1 \log X_1 + b_2 \log X_2 + \epsilon \quad (3)$$

where: Y = predicted weight or volume of firewood,
X = D^2, D^2Th, D^2H4, or D^2Mh,
X_1 = D^2,
X_2 = Th, H4, or Mh,
ϵ = sampling error,
b_i = regression coefficients.

When logarithmic estimates are converted back to original units, they are biased downward because the antilogarithm of an estimated mean gives the geometric rather than the arithmetic mean (Cunia 1964). To account for this bias, a correction factor was computed by using a procedure described by Baskerville (1972) and applied to each model. The equations, including the correction factor, are:

$$Y = 10^{b_0 + b_1 \log X + \frac{S^2_{y \cdot x} \log_e 10}{2} + \epsilon} \quad (4)$$

and

$$Y = 10^{b_0 + b_1 \log X_1 + b_2 \log X_2 + \frac{S^2_{y \cdot x} \log_e 10}{2} + \epsilon} \quad (5)$$

$S^2_{y \cdot x}$ = error mean square from regression analysis

Equations (4) and (5) can be simplified to:

$$Y = a' X^{b_1} \quad (6)$$

and

$$Y = a' X_1^{b_1} X_2^{b_2} \quad (7)$$

where: $a' = 10^{b_0 + \frac{S^2_{y \cdot x} \log_e 10}{2}}$

CHARACTERISTICS OF HARD HARDWOOD AND SOFT HARDWOOD SAMPLE TREES

Hardwoods are generally classified into hard hardwood and soft hardwood groups based on their wood density expressed as specific gravity or dry weight per unit volume. In this study, however, the species were classified into hard and soft hardwood groups based on their green weight per cubic foot and tree form, because the objective was to develop equations for estimating the green weight of firewood in the total tree by species groups. The average green weight of stem wood and bark per cubic foot of wood ranged from 80 pounds for chestnut oak to 73 pounds for hickory and averaged 76 pounds for all the hard hardwood trees sampled (table 2). The green weight of stem wood and bark per cubic foot of wood averaged 65 pounds for the soft hardwoods.

Average stem wood specific gravity was 0.601 for the hard hardwoods compared to 0.462 for the soft hardwoods (table 2). The average stem wood green moisture content was considerably higher in the soft hardwoods (99 percent) than in the hard hardwoods (76 percent). White ash, a hard hardwood with an average specific gravity of 0.572, had a low moisture content (46 percent) resulting in an average green

Table 2.--Average green wood moisture content and specific gravity and green weight of wood and bark per cubic foot of wood for stem to a 4-inch top by species

Species	Average stem wood		Average and standard deviation for weight of wood and bark per cubic foot of stem wood
	Specific gravity	Moisture content	
		Percent	Pounds
		HARD HARDWOODS	
Northern red oak	0.574	83	75 ± 1.9
Southern red oak	.587	79	79 ± 1.9
Scarlet oak	.595	80	78 ± 2.3
Chestnut oak	.622	70	80 ± 3.0
White oak	.621	72	75 ± 2.0
Water oak	.566	88	78 ± 2.9
Hickory	.658	54	73 ± 2.7
Average hard hardwoods	.601	76	76 ± 3.2
		SOFT HARDWOODS	
Yellow-poplar	0.412	108	63 ± 5.0
Sweetgum	.474	118	72 ± 4.0
Blackgum	.475	105	66 ± 6.3
Red maple	.514	80	66 ± 5.6
White ash	.572	46	61 ± 3.6
Average soft hardwoods	.462	99	65 ± 5.9

weight per cubic foot of only 61 pounds, the lowest of all species sampled. Thus, white ash was grouped with the soft hardwoods in this study.

Tree form determines the distribution of wood between stem and crown and consequently the amount of firewood in the crown available for harvesting. The hard hardwood trees sampled exhibited decurrent or deliquescent branching with lateral branches growing almost as fast as the terminal stem, and with the central stem becoming lost in the upper crown. In comparison, the soft hardwood trees generally exhibited excurrent branching with the main stem or terminal bud outgrowing the lateral branches, resulting in cone-shaped crowns. All firewood $\geq$ 4 inches d.o.b. was in the stem to a 4-inch top of pulpwood-size trees (5.0 to 10.9 inches d.b.h.) for hard hardwoods or soft hardwoods and none was in the crown (table 3). The proportion of total tree firewood in the crown of hard hardwood sawtimber trees (trees $\geq$ 11.0 inches) increased from 2 percent in 12-inch trees to 19 or 20 percent in 22- and 24-inch trees and averaged 13 percent. The soft hardwood sawtimber-size trees had on the average only 6 percent of their total firewood in branches. The proportion of total tree firewood in the stem above the saw-log merchantable top decreased with increasing tree size and averaged 19 and 16 percent respectively for sawtimber-size hard hardwood and soft hardwood trees. The northern red and white oaks sampled had the highest proportion (15 percent) and the yellow-poplar and red maples the lowest proportion (4 percent) of branch firewood (table 4).

PREDICTION EQUATIONS

A series of equations were developed to predict the green weight of wood and bark, volume of wood in firewood 4 inches d.o.b. and larger in the total tree, main stem to a 4-inch top, and topwood in sawtimber-size trees. Since tree heights are measured to different top limits by various organizations, equations were developed using D^2 alone and

Table 3.--Average green weight of wood and bark in firewood in the total tree and distribution of wood and bark by tree components for hard hardwoods and soft hardwoods by d.b.h. classes

D.b.h. class (inches)	Average d.b.h.	Average total height	Sample trees	Total tree firewood [1]	Proportion of wood and bark in:		
					Saw-log stem	Stem [2] or stem above saw-log top	Crown ≥ 4 inches d.b.h.
	Inches	Feet	Number	Pounds	------Percent------		
			PULPWOOD-SIZE TREES--HARD HARDWOODS				
6	6.0	54	31	243	--	100	0
8	8.1	66	37	614	--	100	0
10	10.1	72	34	1102	--	100	0
Average	--	--	--	664	--	100	0
			PULPWOOD-SIZE TREES--SOFT HARDWOODS				
6	6.0	59	38	218	--	100	0
8	8.0	66	34	492	--	100	0
10	10.0	78	39	957	--	100	0
Average	--	--	--	562	--	100	0
			SAWTIMBER-SIZE TREES--HARD HARDWOODS				
12	12.0	77	29	1,750	68	30	2
14	14.1	86	30	2,760	69	23	8
16	16.0	88	28	3,791	68	21	11
18	18.0	93	27	5,242	68	18	14
20	19.8	95	19	6,243	67	18	15
22	21.9	102	9	8,932	69	11	20
24	24.0	102	3	10,943	70	11	19
Average	--	--	--	4,284	68	19	13
			SAWTIMBER-SIZE TREES--SOFT HARDWOODS				
12	11.9	85	32	1,568	68	31	1
14	14.1	90	32	2,367	76	20	4
16	16.1	95	29	3,349	78	16	6
18	18.1	101	24	4,575	77	15	8
20	20.0	101	19	5,722	75	15	10
22	21.8	122	5	7,588	84	10	6
24	24.3	137	3	9,039	91	6	3
26	25.6	128	1	12,221	83	15	2
28	28.4	129	1	13,453	88	9	3
Average	--	--	--	3,646	78	16	6

[1] Firewood is all wood 4 inches d.o.b. and larger.

[2] Stem from stump to 4-inch top.

Table 4.--Average green weight of firewood in the total tree for sawtimber-size trees and distribution of firewood in stem and branches by species

Species	Average d.b.h. 1/	Total tree firewood weight 2/	Proportion of tree firewood in:	
			Stem 3/	Branches
	Inches	Pounds	- - - - Percent - - - -	
		HARD HARDWOODS		
Northern red oak	17.6	5,603	85	15
Southern red oak	15.6	3,114	88	12
Scarlet oak	15.2	3,273	90	10
Chestnut oak	16.1	4,052	89	11
White oak	15.8	3,824	85	15
Water oak	16.3	3,846	89	11
Hickory	15.5	3,905	93	7
Average hard hardwoods	16.3	4,284	87	13
		SOFT HARDWOODS		
Yellow-poplar	16.8	4,201	96	4
Sweetgum	16.3	3,844	91	9
Blackgum	15.1	2,987	93	7
Red maple	14.2	2,193	96	4
White ash	14.4	2,247	93	7
Average soft hardwoods	16.1	3,646	94	6

1/ Sawtimber trees are trees $\geq$ 11.0 inches d.b.h.

2/ Firewood is all wood 4 inches d.o.b. and larger.

3/ Stem from stump to 4-inch top.

in combination with Th, H4, and Mh as independent variables. When Th and H4 were used with D^2, the one-variable Equation (6) was used to predict firewood weights and volumes. When Mh was used with D^2, the two-variable Equation (7) was used since saw-log merchantable height varies independently of d.b.h.

Table 5 presents equations for predicting the green weight of wood and bark in firewood $\geq$ 4 inches d.o.b. in the total tree (stem plus crown), stem to 4-inch top, and sawtimber top using D^2, D^2Th, D^2H4, and D^2 + Mh as independent variables for hard hardwoods and soft hardwoods, respectively. Table 6 presents equations for predicting the volume of wood excluding bark in firewood in the total tree, stem, and sawtimber topwood with each independent variable combination for hard and soft hardwoods, respectively. A method for placing confidence limits about predictions made with the equations is given in the Appendix.

Firewood in branches and the stem above the saw-log top (topwood firewood) is the most variable firewood component of the tree. Equations based on the sawtimber-size trees were developed for predicting weight and volume of topwood firewood with Equations (6) and (7). These equations, however, resulted in poor estimates of topwood firewood at the fringes of the data. Therefore, topwood firewood was estimated by subtracting the predicted weight or volume of the saw-log merchantable stem from the predicted weight or volume of all the firewood in a sawtimber-size tree.

All independent variable combinations were good predictors of firewood in the total tree or main stem, but equations using D^2Th or D^2H4 were the best predictors of

Table 5.--Regression equations for estimating the green weight of wood and bark in firewood ≥ 4 inches d.o.b. in the total tree and its components for hard hardwoods and soft hardwoods using d.b.h. alone and d.b.h. and total height, height to 4-inch top, and saw-log merchantable height as independent variables

Weight in pounds (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]	Sample mean of x[2/] ($\bar{x}$)	Corrected sums of squares for x[2/] $\Sigma(x-\bar{x})^2$	Number trees sampled (N)
	HARD HARDWOODS					
Firewood ≥ 4-inches d.o.b. in the total tree above stump						
	$Y = 1.81235\ (D^2)^{1.37950}$	0.98	0.0767	2.1530	29.9305	247
	$Y = 0.04964\ (D^2Th)^{1.12146}$	.99	.0523	4.0383	45.9040	247
	$Y = 0.36686\ (D^2H4)^{0.94651}$	.99	.0539	3.8672	64.3917	247
	$Y = 1.81993\ (D^2)^{1.16787}(Mh)^{0.31882}$	.95	.0536	--	--	142
Firewood in the stem from stump to 4-inch d.o.b. top						
	$Y = 2.51832\ (D^2)^{1.30019}$	.97	.0806	2.1530	29.9305	247
	$Y = 0.08313\ (D^2Th)^{1.05899}$	.99	.0538	4.0383	45.9040	247
	$Y = 0.53822\ (D^2H4)^{0.89584}$	.99	.0457	3.8672	64.3917	247
	$Y = 3.54329\ (D^2)^{1.00776}(Mh)^{0.34841}$	.94	.0498	--	--	142
Firewood ≥ 4-inches d.o.b. in branches and main stem excluding saw logs						
	$Y = [2.79011\ (D^2)^{1.30051}] - [1.91019\ (D^2)^{1.30062}]$	--	--	--	--	142
	$Y = [0.07890\ (D^2Th)^{1.07503}] - [0.03765\ (D^2Th)^{1.11020}]$	--	--	--	--	142
	$Y = [0.29143\ (D^2H4)^{0.97150}] - [0.13778\ (D^2H4)^{1.00849}]$	--	--	--	--	142
	$Y = [1.81993\ (D^2)^{1.16787}(Mh)^{0.31882}] - [0.66252\ (D^2)^{0.97731}(Mh)^{0.77715}]$	--	--	--	--	142

Continued

Table 5.--Regression equations for estimating the green weight of wood and bark in firewood ≥ 4 inches d.o.b. in the total tree and its components for hard hardwoods and soft hardwoods using d.b.h. alone and d.b.h. and total height, height to 4-inch top, and saw-log merchantable height as independent variables--Continued

Weight in pounds (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y \cdot x}$)[2/]	Sample mean of x[2/] ($\bar{x}$)	Corrected sums of squares for x[2/] $\Sigma(x-\bar{x})^2$	Number trees sampled (N)
	SOFT HARDWOODS					
Firewood ≥ 4 inches d.o.b. in the total tree above stump						
	$Y = 1.61179\ (D^2)^{1.37569}$	0.97	0.0809	2.1326	32.2723	257
	$Y = 0.05064\ (D^2Th)^{1.09701}$	.98	.0742	4.0432	50.9696	257
	$Y = 0.41510\ (D^2H4)^{0.90911}$	.98	.0767	3.8743	74.1006	257
	$Y = 2.40850\ (D^2)^{1.15531}(Mh)^{0.21263}$	.94	.0597	--	--	146
Firewood in the stem from stump to 4-inch d.o.b. top						
	$Y = 1.83967\ (D^2)^{1.34241}$	.97	.0826	2.1326	32.2723	257
	$Y = 0.06160\ (D^2Th)^{1.07239}$	.98	.0709	4.0432	50.9696	257
	$Y = 0.47816\ (D^2H4)^{0.88942}$	.98	.0708	3.8743	74.1006	257
	$Y = 2.84096\ (D^2)^{1.07049}(Mh)^{0.27808}$	.94	.0568	--	--	146
Firewood ≥ 4 inches d.o.b. in branches and stem above saw-log top						
	$Y = [2.73252\ (D^2)^{1.27941}] - [0.86296\ (D^2)^{1.43757}]$	--	--	--	--	146
	$Y = [0.12326\ (D^2Th)^{1.00897}] - [0.01843\ (D^2Th)^{1.16880}]$	--	--	--	--	146
	$Y = [0.30578\ (D^2H4)^{0.94132}] - [0.05039\ (D^2H4)^{1.09502}]$	--	--	--	--	146
	$Y = [2.40850\ (D^2)^{1.15531}(Mh)^{0.21263}] -$ $[0.53556\ (D^2)^{0.99084}(Mh)^{0.76541}]$	--	--	--	--	146

[1/] $Y = a(D^2)^b$ or $Y = a(D^2Th)^b$ or $Y = a(D^2H4)^b$ or $Y = a(D^2)^{b_1}(Mh)^{b_2}$.

where:

Y = component weight in pounds,
D = d.b.h. in inches,
Th = tree total height in feet,
H4 = tree height to 4-inch top in feet,
Mh = saw-log merchantable height in feet,
a, b, b_1, b_2 = regression coefficients.

2/

Table 6.--Regression equations for estimating the volume of wood excluding bark in firewood ≥ 4 inches d.o.b. in the total tree and its components for hard hardwoods and soft hardwoods using d.b.h. alone and d.b.h. and total height, height to 4-inch top, and saw-log merchantable height as independent variables

Cubic-foot volume (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]	Sample mean of x[2/] ($\bar{x}$)	Corrected sums of squares for x[2/] $\Sigma(x-\bar{x})^2$	Number trees sampled (N)
	HARD HARDWOODS					
Firewood ≥ 4 inches d.o.b. in the total tree above stump						
	$Y = 0.02322\ (D^2)^{1.38347}$	0.97	0.0820	2.1530	29.9305	247
	$Y = 0.00062\ (D^2Th)^{1.12612}$	.99	.0543	4.0383	45.9040	247
	$Y = 0.00461\ (D^2H4)^{0.95066}$	.99	.0550	3.8672	64.3917	247
	$Y = 0.02194\ (D^2)^{1.15885}(Mh)^{0.35502}$	.94	.0574	--	--	142
Firewood in the stem from stump to 4-inch d.o.b. top						
	$Y = 0.03156\ (D^2)^{1.30939}$	.97	.0852	2.1530	29.9305	247
	$Y = 0.00100\ (D^2Th)^{1.06772}$	.99	.0557	4.0383	24.9040	247
	$Y = 0.00660\ (D^2H4)^{0.90328}$	.99	.0476	3.8672	64.3917	247
	$Y = 0.04065\ (D^2)^{1.01076}(Mh)^{0.38181}$	.94	.0533	--	--	142
Firewood ≥ 4 inches d.o.b. in branches and stem above saw-log top						
	$Y = [0.03533\ (D^2)^{1.30654}] - [0.02319\ (D^2)^{1.31629}]$	--	--	--	--	142
	$Y = [0.00092\ (D^2Th)^{1.08624}] - [0.00042\ (D^2Th)^{1.12820}]$	--	--	--	--	142
	$Y = [0.00341\ (D^2H4)^{0.98269}] - [0.00154\ (D^2H4)^{1.02566}]$	--	--	--	--	142
	$Y = [0.02194\ (D^2)^{1.15885}(Mh)^{0.35502}] -$ $[0.00771\ (D^2)^{0.98039}(Mh)^{0.80741}]$	--	--	--	--	142

Continued

Table 6.--Regression equations for estimating the volume of wood excluding bark in firewood ≥ 4 inches d.o.b. in the total tree and its components for hard hardwoods and soft hardwoods using d.b.h. alone and d.b.h. and total height, height to 4-inch top, and saw-log merchantable height as independent variables--Continued

Cubic-foot volume (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]	Sample mean of x[2/] ($\bar{x}$)	Corrected sums of squares for x[2/] $(x-\bar{x})^2$	Number trees sampled (N)
	SOFT HARDWOODS					
Firewood ≥ 4 inches d.o.b. in the total tree above stump						
	$Y = 0.02584\ (D^2)^{1.36734}$	0.97	0.0812	2.1326	32.2723	257
	$Y = 0.00080\ (D^2Th)^{1.09368}$	.98	.0643	4.0432	50.9696	257
	$Y = 0.00655\ (D^2H4)^{0.90589}$	.98	.0689	3.8743	74.1006	257
	$Y = 0.03485\ (D^2)^{1.13539}(Mh)^{0.25475}$	.95	.0552	--	--	146
Firewood in the stem from stump to 4-inch d.o.b. top						
	$Y = 0.02915\ (D^2)^{1.33721}$	.97	.0846	2.1326	32.2723	257
	$Y = 0.00096\ (D^2Th)^{1.07149}$	.98	.0631	4.0432	50.9696	257
	$Y = 0.00745\ (D^2H4)^{0.88813}$	.98	.0652	3.8743	74.1006	257
	$Y = 0.04007\ (D^2)^{1.05670}(Mh)^{0.31952}$	.94	.0560	--	--	146
Firewood ≥ 4 inches d.o.b. in branches and stem above saw-log top						
	$Y = [0.04057\ (D^2)^{1.28407}] - [0.01287\ (D^2)^{1.44359}]$	--	--	--	--	146
	$Y = [0.00152\ (D^2Th)^{1.02969}] - [0.00023\ (D^2Th)^{1.18984}]$	--	--	--	--	146
	$Y = [0.00386\ (D^2H4)^{0.96000}] - [0.00064\ (D^2H4)^{1.11420}]$	--	--	--	--	146
	$Y = [0.03485\ (D^2)^{1.13539}(Mh)^{0.25475}] - [0.00778\ (D^2)^{0.97403}(Mh)^{0.80452}]$	--	--	--	--	146

1/ $Y = a(D^2)^b$ or $Y = a(D^2Th)^b$ or $Y = a(D^2H4)^b$ or $Y = a(D^2)^b \cdot (Mh)^{b_2}$.

where:

Y = component volume in cubic feet,
D = d.b.h. in inches,
Th = tree total height in feet,
H4 = tree height to 4-inch top in feet,
Mh = saw-log merchantable height in feet,
a, b, b_1, b_2 = regression coefficients.

2/ $\log_{10}$ form.

otal tree and stem firewood. Equations for estimating top-
vood firewood in sawtimber-size trees by subtracting saw-
og stem from total tree weight or volume were developed
or all independent variable combinations. However, the
est prediction of topwood firewood is the equation based
n d.b.h. and saw-log merchantable height, since this is the
nly equation that contains a direct estimate of the saw-log
naterial removed from the tree. When average tree heights
re similar to those of our sample trees, the equations using
l.b.h. alone will result in good estimates of total tree and
tem firewood. However, when average tree heights are dif-
erent, the equations that include a height variable should
e applied directly or used to develop local weight/volume
ables based on d.b.h. only.

FIREWOOD TABLES

Equations based on $D^2 + Mh$, D^2H4, and D^2Th from tables 5 and 6 were used to develop tables of firewood weights in pounds and volume in cords. In this paper, a cord of split, stacked firewood is assumed to contain 78 cubic feet of solid wood. A 2 percent loss in wood and bark as sawdust is assumed when processing the trees into firewood sticks (Monahan and Wartluft 1980). Tables 7 to 12 (Appendix) show predicted green weight of wood and bark and volume of wood in firewood in the total tree (stem plus crown), stem to 4-inch d.o.b. top, and sawtimber top by d.b.h. and saw-log merchantable height classes for hard hardwoods and soft hardwoods. Tables 13 to 16 (Appendix) show firewood weights and volumes by d.b.h. and heights to 4-inch top for the total tree and for the stem to a 4-inch d.o.b. top. Tables 17 to 20 (Appendix) show firewood weights and volumes by d.b.h. and total height classes for the total tree and stem to a 4-inch top. Trees equal to or less than 10 inches d.b.h. had no firewood $\geq$ 4-inch d.o.b. in their crowns. Thus, the same equation used to estimate firewood in the stem to 4-inch top was used to estimate total tree firewood in these size trees.

Sawtimber-size trees capable of producing quality saw logs should be marketed for saw logs and only the upper stem and crown utilized for firewood. Tables for estimating firewood in the stem of sawtimber-size trees are presented to facilitate firewood estimation in poor-quality hardwoods.

Firewood in similar-size trees may vary in weight and volume because of species differences in crown size, stem taper, and weight per cubic foot. Therefore, these weight equations and tables have a slight bias when applied to a single species. Table 21 (Appendix) presents factors for correcting for this bias when the tables are applied to a single species. The equations and tables should be applied to trees growing in natural, fully stocked forest stands and not to open-grown trees. The tables will give best results when applied to large numbers of trees.

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COMPUTATION OF CONFIDENCE LIMITS

Tables 5 and 6 contain the standard errors of the estimate, the sample mean of x, and the corrected sums of squares for x for each equation in $\log_{10}$ form. These statistics can be used to calculate approximate confidence limits in pounds or cubic feet by using a modification of Cox's formula (Land 1972) for estimating confidence limits for lognormal means:

$$Y_{U,L} = 10^{\log Y \pm Z \sqrt{S^2_{y \cdot x}\left[\frac{1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x-\bar{x})^2}\right] + \frac{S^4_{y \cdot x}}{2(n+1)}}} \quad (8)$$

where:

$Y_{U,L}$ = upper and lower limits for Y,
Y = predicted weight or volume of firewood from Equation (6),
Z = value from the standard normal table for appropriate confidence level,
$S_{y \cdot x}$ = standard error of estimate for prediction equation,
n = number of observations used to develop equation,
$\bar{x}$ = sample mean of log x – (from table of equations),
$\Sigma(x-\bar{x})^2$ = corrected sums of squares for log x – (from table of equations),
x = value of independent variable in $\log_{10}$ form.

Cox's method of approximation sufficiently estimates actual confidence limits when applied to samples with small variances as occur in the total tree and stem weight and volume firewood data sets. Thus, Equation (8) should be used to approximate confidence limits for the single variable equations presented in this Paper.

APPENDIX

Table 7.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem plus crown for hard hardwoods by d.b.h. and saw-log merchantable height

D.b.h. class (inches)	Merchantable height (logs)[1/ 2/]								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
					Pounds[3/]				
11	1187	1346	1473	1580	1674				
12	1454	1650	1805	1936	2051				
13	1753	1989	2176	2334	2473	2596	2708		
14	2084	2365	2588	2776	2940	3087	3220		
15	2449	2778	3040	3261	3454	3626	3783	3926	
16	2847	3230	3535	3792	4016	4216	4398	4565	
17	3281	3721	4072	4368	4627	4858	5067	5260	
18	3749	4253	4654	4992	5288	5551	5791	6011	
19		4825	5280	5664	5999	6299	6570	6820	7051
20		5440	5952	6385	6763	7100	7407	7688	7949
21		6096	6671	7156	7579	7957	8301	8616	8908
22		6796	7437	7977	8449	8871	9253	9605	9931
23		7539	8250	8850	9374	9841	10266	10656	11017
24		8327	9113	9775	10354	10870	11339	11770	12169
25		9160	10024	10753	11389	11958	12473	12947	13386
					Cords[4/]				
11	0.195	0.224	0.247	0.268	0.285				
12	0.238	0.274	0.303	0.327	0.349				
13	0.286	0.330	0.364	0.394	0.420	0.444	0.465		
14	0.340	0.391	0.433	0.468	0.499	0.527	0.552		
15	0.399	0.459	0.508	0.549	0.585	0.618	0.648	0.675	
16	0.464	0.533	0.590	0.638	0.680	0.718	0.752	0.784	
17	0.534	0.614	0.679	0.734	0.782	0.826	0.866	0.902	
18	0.609	0.701	0.775	0.838	0.893	0.943	0.988	1.030	
19		0.794	0.878	0.950	1.013	1.069	1.120	1.168	1.212
20		0.895	0.989	1.070	1.140	1.204	1.262	1.315	1.365
21		1.002	1.108	1.198	1.277	1.348	1.413	1.473	1.529
22		1.116	1.234	1.334	1.422	1.501	1.574	1.640	1.703
23		1.237	1.368	1.479	1.577	1.664	1.744	1.818	1.887
24		1.365	1.509	1.632	1.740	1.837	1.925	2.007	2.083
25		1.501	1.659	1.794	1.913	2.019	2.116	2.206	2.290

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [1.81993(D^2)^{1.16787}(Mh)^{0.31882}]0.98$.

[4/] $Y = [0.2194(D^2)^{1.15885}(Mh)^{0.35502}]/79.6$.

Table 8.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem plus crown for soft hardwoods by d.b.h. and saw-log merchantable height

D.b.h. class (inches)	Merchantable height (logs)[1/ 2/]								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Pounds[3/]								
11	1096	1192	1266	1327	1378				
12	1340	1457	1548	1622	1685				
13	1612	1754	1862	1951	2028	2095	2154		
14	1913	2081	2210	2316	2406	2486	2557		
15	2244	2441	2592	2716	2822	2915	2999	3074	
16	2605	2833	3009	3153	3276	3384	3481	3569	
17		3259	3461	3627	3769	3893	4004	4105	4198
18		3720	3950	4139	4301	4443	4570	4685	4790
19		4214	4476	4690	4873	5034	5178	5308	5428
20		4745	5039	5280	5486	5668	5829	5976	6111
21		5311	5640	5910	6141	6344	6525	6689	6840
22		5914	6280	6581	6838	7064	7266	7448	7616
23			6959	7293	7578	7828	8051	8254	8440
24			7678	8046	8361	8637	8883	9107	9312
25			8438	8842	9188	9491	9762	10008	10233
	Cords[4/]								
11	0.208	0.230	0.247	0.262	0.274				
12	0.254	0.280	0.301	0.319	0.334				
13	0.304	0.336	0.361	0.382	0.400	0.416	0.430		
14	0.360	0.398	0.428	0.452	0.474	0.492	0.509		
15	0.421	0.465	0.500	0.529	0.554	0.576	0.596	0.614	
16	0.487	0.539	0.579	0.613	0.641	0.667	0.690	0.710	
17		0.618	0.665	0.703	0.736	0.765	0.791	0.815	0.837
18		0.704	0.757	0.800	0.838	0.871	0.901	0.928	0.953
19		0.796	0.856	0.905	0.947	0.985	1.019	1.050	1.078
20		0.894	0.961	1.017	1.064	1.107	1.145	1.179	1.211
21		0.999	1.074	1.136	1.189	1.236	1.279	1.317	1.353
22		1.111	1.193	1.262	1.322	1.374	1.421	1.464	1.504
23			1.320	1.396	1.462	1.520	1.572	1.620	1.663
24			1.454	1.538	1.610	1.674	1.732	1.784	1.832
25			1.595	1.687	1.767	1.837	1.900	1.957	2.010

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [2.40850(D^2)^{1.15531}(Mh)^{0.21263}]0.98$.

[4/] $Y = [0.03485(D^2)^{1.13539}(Mh)^{0.25475}]/79.6$.

Table 9.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem to 4-inch top for hard hardwoods by d.b.h. and saw-log merchantable height

D.b.h. class (inches)	Merchantable height (logs)[1/ 2/]								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	-Pounds[3/]								
11	1165	1338	1476	1594	1697				
12	1389	1594	1759	1899	2022				
13	1632	1873	2067	2232	2376	2506	2625		
14	1895	2175	2400	2591	2759	2910	3047		
15	2178	2499	2758	2978	3171	3344	3502	3648	
16	2480	2847	3141	3391	3611	3809	3989	4154	
17	2802	3216	3549	3832	4081	4304	4507	4694	
18	3145	3609	3983	4300	4579	4829	5057	5268	5463
19		4025	4441	4795	5106	5385	5639	5874	6092
20		4463	4925	5318	5662	5972	6254	6514	6756
21		4924	5434	5867	6247	6589	6900	7187	7454
22		5408	5968	6444	6862	7236	7578	7893	8187
23		5915	6527	7048	7505	7915	8289	8633	8954
24		6445	7112	7679	8177	8624	9031	9406	9756
25		6998	7722	8337	8878	9363	9805	10213	10592
	-Cords[4/]								
11	0.191	0.222	0.248	0.269	0.288				
12	0.228	0.265	0.295	0.321	0.344				
13	0.268	0.311	0.347	0.377	0.404	0.429	0.451		
14	0.311	0.362	0.403	0.438	0.470	0.498	0.524		
15	0.358	0.416	0.463	0.504	0.540	0.572	0.602	0.629	
16	0.408	0.474	0.528	0.574	0.615	0.652	0.686	0.717	
17	0.461	0.536	0.597	0.649	0.695	0.737	0.775	0.811	0.844
18	0.517	0.601	0.670	0.729	0.781	0.827	0.870	0.910	0.947
19		0.671	0.747	0.813	0.871	0.923	0.971	1.015	1.057
20		0.744	0.829	0.902	0.966	1.024	1.077	1.126	1.172
21		0.821	0.915	0.995	1.066	1.130	1.189	1.243	1.293
22		0.902	1.005	1.093	1.171	1.241	1.306	1.365	1.421
23		0.987	1.099	1.196	1.281	1.358	1.428	1.494	1.555
24		1.076	1.198	1.303	1.396	1.480	1.557	1.628	1.694
25		1.168	1.301	1.415	1.516	1.607	1.691	1.768	1.840

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [3.54329(D^2)^{1.00776}(Mh)^{0.34841}]0.98$.

[4/] $Y = [0.04065\ (D^2)^{1.01076}(Mh)^{0.38181}]/79.6$.

Table 10.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem to 4-inch top for soft hardwoods by d.b.h. and saw-log merchantable top

D.b.h. class (inches)	Merchantable height (logs)[1/] [2/]								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Pounds[3/]								
11	1035	1156	1250	1329	1397				
12	1247	1392	1506	1601	1683				
13	1480	1652	1788	1900	1998	2085	2163		
14	1735	1937	2095	2227	2342	2443	2535		
15	2011	2245	2428	2582	2714	2832	2938	3035	
16	2309	2577	2788	2964	3117	3252	3374	3485	
17		2935	3175	3375	3549	3702	3841	3968	4086
18		3317	3588	3814	4010	4184	4341	4485	4617
19		3724	4028	4282	4503	4698	4874	5035	5184
20		4156	4496	4780	5025	5243	5440	5620	5786
21		4614	4991	5306	5579	5821	6039	6239	6423
22		5097	5513	5861	6163	6430	6671	6892	7096
23			6064	6447	6778	7072	7338	7580	7804
24			6642	7062	7425	7747	8038	8303	8548
25			7249	7707	8103	8454	8772	9062	9329
	Cords[4/]								
11	0.197	0.223	0.245	0.262	0.278				
12	0.237	0.269	0.294	0.315	0.334				
13	0.280	0.318	0.348	0.373	0.396	0.415	0.433		
14	0.328	0.372	0.407	0.437	0.463	0.486	0.507		
15	0.379	0.430	0.471	0.505	0.535	0.562	0.586	0.609	
16	0.435	0.493	0.540	0.579	0.614	0.644	0.672	0.698	
17		0.561	0.614	0.658	0.697	0.732	0.764	0.793	0.820
18		0.633	0.692	0.743	0.787	0.826	0.862	0.895	0.925
19		0.709	0.776	0.833	0.882	0.926	0.966	1.003	1.037
20		0.790	0.865	0.928	0.983	1.032	1.077	1.118	1.156
21		0.876	0.959	1.029	1.090	1.145	1.194	1.240	1.282
22		0.967	1.058	1.135	1.203	1.263	1.317	1.368	1.414
23			1.163	1.247	1.321	1.387	1.447	1.502	1.553
24			1.272	1.365	1.446	1.518	1.583	1.644	1.700
25			1.387	1.488	1.576	1.655	1.726	1.792	1.853

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [2.84096(D^2)^{1.07049}(Mh)^{0.27808}]0.98$.

[4/] $Y = [0.04007(D^2)^{1.05670}(Mh)^{0.31952}]/79.6$.

Table 11.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem and crown above the saw-log top for hard hardwoods by d.b.h. and saw-log merchantable height

D.b.h. class (inches)	Merchantable height (logs)[1/] [2/]								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Pounds[3/]								
11	555	488	404	312	214				
12	706	632	538	432	321				
13	878	799	694	576	449	318	183		
14	1073	989	874	743	601	453	301		
15	1292	1204	1079	935	778	613	443	269	
16	1534	1445	1311	1153	980	798	609	416	
17	1802	1711	1568	1397	1209	1009	801	588	371
18	2096	2005	1854	1670	1466	1248	1021	787	548
19		2327	2168	1972	1751	1515	1269	1014	753
20		2678	2512	2303	2067	1813	1546	1270	986
21		3058	2887	2666	2414	2141	1853	1555	1249
22		3469	3292	3059	2792	2500	2192	1872	1543
23		3910	3730	3486	3203	2893	2564	2221	1868
24		4383	4200	3946	3647	3319	2969	2603	2226
25		4889	4703	4439	4126	3779	3408	3019	2617
	Cords[4/]								
11	0.090	0.081	0.068	0.053	0.037				
12	0.115	0.104	0.089	0.072	0.054				
13	0.142	0.131	0.115	0.096	0.075	0.053	0.031		
14	0.173	0.162	0.144	0.123	0.100	0.075	0.050		
15	0.208	0.196	0.177	0.154	0.129	0.101	0.073	0.043	
16	0.247	0.235	0.215	0.190	0.161	0.131	0.100	0.067	
17	0.289	0.278	0.256	0.229	0.199	0.166	0.131	0.095	0.058
18	0.336	0.325	0.302	0.273	0.240	0.204	0.166	0.127	0.086
19		0.376	0.353	0.322	0.286	0.247	0.206	0.163	0.199
20		0.432	0.408	0.375	0.337	0.295	0.251	0.204	0.156
21		0.493	0.468	0.434	0.393	0.348	0.301	0.250	0.198
22		0.558	0.533	0.497	0.454	0.406	0.355	0.301	0.245
23		0.629	0.603	0.566	0.520	0.470	0.415	0.357	0.297
24		0.704	0.678	0.640	0.592	0.538	0.480	0.419	0.354
25		0.784	0.759	0.719	0.669	0.612	0.551	0.485	0.417

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [1.81993(D^2)^{1.16787}(Mh)^{0.31882}] - [0.66252(D^2)^{0.97731}(Mh)^{0.77715}]$.

[4/] $Y = [[0.02194(D^2)^{1.15885}(Mh)^{0.35502}] - [0.00771(D^2)^{0.98039}(Mh)^{0.80741}]]/79.6$.

Table 12.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem and crown above the saw-log top for soft hardwoods by d.b.h. and saw-log merchantable height

D.b.h. class (inches)	Merchantable height (logs)[1/ 2/]								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	-Pounds[3/]								
11	569	479	381	279	176				
12	714	610	496	377	256				
13	879	761	630	493	353	212	71		
14	1064	931	783	626	467	306	144		
15	1270	1123	955	779	599	416	233	49	
16	1498	1335	1149	952	749	544	338	131	
17		1570	1364	1145	919	690	460	229	
18		1828	1601	1359	1110	856	600	343	87
19		2109	1861	1596	1321	1041	759	476	192
20		2414	2144	1855	1554	1248	938	627	315
21		2743	2452	2137	1810	1475	1137	797	456
22		3098	2784	2443	2088	1725	1357	987	615
23			3141	2774	2391	1997	1599	1198	795
24			3525	3130	2717	2293	1863	1430	994
25			3934	3512	3069	2613	2150	1684	1214
	-Cords[4/]								
11	0.107	0.091	0.073	0.053	0.033				
12	0.134	0.116	0.095	0.072	0.049				
13	0.164	0.144	0.120	0.094	0.067	0.039	0.011		
14	0.198	0.176	0.149	0.119	0.089	0.057	0.025		
15	0.236	0.211	0.181	0.148	0.114	0.078	0.042	0.005	
16	0.278	0.251	0.217	0.181	0.142	0.102	0.062	0.020	
17		0.294	0.257	0.217	0.174	0.130	0.085	0.039	
18		0.342	0.302	0.257	0.210	0.161	0.111	0.060	0.009
19		0.393	0.350	0.301	0.250	0.196	0.141	0.085	0.029
20		0.449	0.402	0.350	0.293	0.235	0.175	0.113	0.052
21		0.510	0.459	0.402	0.341	0.277	0.212	0.145	0.078
22		0.575	0.521	0.459	0.393	0.324	0.253	0.181	0.108
23			0.587	0.521	0.449	0.375	0.298	0.220	0.141
24			0.657	0.586	0.510	0.430	0.348	0.264	0.178
25			0.732	0.657	0.576	0.490	0.402	0.311	0.219

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [2.40850(D^2)^{1.15531}(Mh)^{0.21263}] - [0.53556(D^2)^{0.99084}(Mh)^{0.76541}]$.

[4/] $Y = [[0.03485(D^2)^{1.13539}(Mh)^{0.25475}] - [0.00778(D^2)^{0.97403}(Mh)^{0.80452}]]/79.6$.

Table 13.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem plus crown for hard hardwoods by d.b.h. and height to 4-inch d.o.b. top

D.b.h. class (inches)	Height to 4-inch top (feet)[1/ 2/]								
	10	20	30	40	50	60	70	80	90
	Pounds[3/ 4/]								
5	74	138	199	257	314				
6	103	191	275	356	435	512			
7		252	363	469	573	675	775		
8		320	461	596	728	857	984		
9			569	736	899	1059	1216	1370	
10			687	889	1086	1279	1468	1655	1839
11			842	1105	1365	1622	1877	2130	2381
12			993	1303	1610	1913	2213	2511	2808
13			1155	1516	1873	2226	2575	2922	3267
14			1329	1745	2155	2561	2963	3363	3759
15				1988	2456	2918	3377	3832	4284
16				2247	2775	3298	3816	4330	4840
17				2520	3112	3699	4280	4856	5429
18				2808	3468	4121	4769	5411	6049
19				3110	3842	4565	5282	5994	6701
20					4233	5031	5821	6605	7384
21					4643	5518	6384	7244	8099
22					5071	6026	6972	7911	8844
23					5516	6555	7584	8606	9621
24						7104	8220	9328	10428
25						7675	8881	10077	11266
	Cords[5/ 6/]								
5	0.012	0.023	0.033	0.043	0.052				
6	0.017	0.032	0.046	0.059	0.072	0.085			
7		0.042	0.060	0.078	0.095	0.113	0.129		
8		0.053	0.077	0.099	0.122	0.143	0.165		
9			0.095	0.123	0.150	0.177	0.204	0.230	
10			0.115	0.149	0.182	0.214	0.247	0.278	0.309
11			0.140	0.184	0.228	0.271	0.314	0.356	0.399
12			0.166	0.218	0.269	0.320	0.370	0.421	0.470
13			0.193	0.253	0.313	0.373	0.431	0.490	0.548
14			0.222	0.292	0.361	0.429	0.497	0.564	0.631
15				0.333	0.411	0.489	0.566	0.643	0.719
16				0.376	0.465	0.553	0.640	0.727	0.813
17				0.422	0.522	0.620	0.718	0.816	0.912
18				0.470	0.582	0.692	0.801	0.909	1.017
19				0.521	0.645	0.767	0.888	1.008	1.127
20					0.711	0.845	0.978	1.111	1.242
21					0.780	0.927	1.074	1.219	1.363
22					0.852	1.013	1.173	1.332	1.489
23					0.927	1.102	1.276	1.449	1.621
24						1.195	1.384	1.571	1.757
25						1.292	1.495	1.698	1.899

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] Trees 5-10 inches d.b.h. $Y = [0.53822(D^2H4)^{0.89584}]0.98$.

[4/] Trees > 10 inches d.b.h. $Y = [0.36686(D^2H4)^{0.94651}]0.98$.

[5/] Trees 5-10 inches d.b.h. $Y = [0.00660(D^2H4)^{0.90328}]/79.6$.

[6/] Trees > 10 inches d.b.h. $Y = [0.00461(D^2H4)^{0.95066}]/79.6$.

Table 14.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem plus crown for soft hardwoods by d.b.h. and height to 4-inch d.o.b. top

D.b.h. class (inches)	Height to 4-inch top (feet)[1/ 2/]								
	10	20	30	40	50	60	70	80	90
	Pounds[3/ 4/]								
5	64	118	169	218	266				
6	88	163	234	302	368	433			
7		214	308	397	484	570	653		
8		272	390	504	614	722	829	933	
9			481	621	757	891	1022	1151	1278
10			580	749	914	1074	1232	1388	1541
11			701	911	1115	1316	1514	1710	1903
12			821	1067	1307	1542	1774	2003	2229
13			950	1234	1511	1784	2052	2317	2579
14			1087	1412	1729	2041	2348	2651	2951
15				1600	1960	2314	2662	3005	3345
16				1800	2204	2602	2993	3379	3761
17				2009	2461	2905	3342	3773	4200
18				2229	2731	3223	3708	4187	4660
19				2460	3013	3556	4091	4619	5141
20					3307	3904	4491	5071	5644
21					3614	4266	4908	5541	6167
22					3933	4642	5341	6030	6711
23					4264	5033	5790	6538	7276
24						5438	6256	7064	7862
25						5857	6738	7608	8468
	Cords[5/ 6/]								
5	0.013	0.023	0.033	0.043	0.053				
6	0.017	0.032	0.046	0.060	0.073	0.086			
7		0.042	0.061	0.079	0.096	0.113	0.129		
8		0.054	0.077	0.100	0.121	0.143	0.164	0.184	
9			0.095	0.123	0.150	0.176	0.202	0.227	0.252
10			0.115	0.148	0.180	0.212	0.243	0.274	0.304
11			0.138	0.179	0.219	0.259	0.298	0.336	0.374
12			0.162	0.210	0.257	0.303	0.348	0.393	0.437
13			0.187	0.243	0.297	0.350	0.403	0.455	0.506
14			0.214	0.277	0.340	0.401	0.461	0.520	0.578
15				0.314	0.385	0.454	0.522	0.589	0.655
16				0.353	0.433	0.510	0.587	0.662	0.737
17				0.394	0.483	0.569	0.655	0.739	0.822
18				0.437	0.535	0.632	0.726	0.820	0.912
19				0.482	0.591	0.697	0.801	0.904	1.006
20					0.648	0.764	0.879	0.992	1.104
21					0.708	0.835	0.960	1.084	1.206
22					0.770	0.908	1.045	1.179	1.312
23					0.835	0.985	1.132	1.278	1.422
24						1.064	1.223	1.380	1.536
25						1.145	1.317	1.486	1.654

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] Trees 5-10 inches d.b.h. $Y = [0.47816(D^2H4)^{0.88942}]0.98.$

[4/] Trees > 10 inches d.b.h. $Y = [0.41510(D^2H4)^{0.90911}]0.98.$

[5/] Trees 5-10 inches d.b.h. $Y = [0.00745(D^2H4)^{0.88813}]/79.6.$

[6/] Trees > 10 inches d.b.h. $Y = [0.00655(D^2H4)^{0.90589}]/79.6.$

Table 15.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem to 4-inch top for hard hardwoods by d.b.h. and height to 4-inch d.o.b. top

D.b.h. class (inches)	Height to 4-inch top (feet)[1/ 2/]								
	10	20	30	40	50	60	70	80	90
	Pounds[3/]								
5	74	138	199	257	314				
6	103	191	275	356	435	512			
7		252	363	469	573	675	775		
8		320	461	596	728	857	984		
9			569	736	899	1059	1216	1370	
10			687	889	1086	1279	1468	1655	1839
11			815	1055	1288	1517	1742	1963	2181
12			953	1233	1506	1773	2035	2294	2549
13			1100	1423	1738	2046	2349	2648	2942
14			1256	1625	1985	2337	2683	3024	3360
15				1839	2246	2644	3036	3422	3802
16				2064	2521	2968	3408	3841	4268
17				2301	2810	3309	3799	4282	4758
18				2549	3113	3666	4209	4743	5271
19				2809	3430	4039	4637	5226	5808
20					3760	4427	5083	5729	6367
21					4104	4832	5547	6252	6948
22					4460	5252	6030	6796	7552
23					4830	5687	6529	7359	8178
24						6138	7047	7942	8826
25						6604	7582	8545	9496
	Cords[4/]								
5	0.012	0.023	0.033	0.043	0.052				
6	0.017	0.032	0.046	0.059	0.072	0.085			
7		0.042	0.060	0.078	0.095	0.113	0.129		
8		0.053	0.077	0.099	0.122	0.143	0.165		
9			0.095	0.123	0.150	0.177	0.204	0.230	
10			0.115	0.149	0.182	0.214	0.247	0.278	0.309
11			0.136	0.177	0.216	0.255	0.293	0.330	0.367
12			0.159	0.207	0.253	0.298	0.343	0.387	0.430
13			0.184	0.239	0.292	0.345	0.396	0.447	0.497
14			0.211	0.273	0.334	0.394	0.453	0.511	0.568
15				0.309	0.378	0.446	0.513	0.579	0.643
16				0.348	0.425	0.501	0.576	0.650	0.723
17				0.388	0.474	0.559	0.643	0.725	0.807
18				0.430	0.526	0.620	0.713	0.804	0.895
19				0.474	0.580	0.684	0.786	0.887	0.986
20					0.636	0.750	0.862	0.973	1.082
21					0.695	0.819	0.942	1.062	1.182
22					0.756	0.891	1.024	1.156	1.285
23					0.819	0.966	1.110	1.252	1.393
24						1.043	1.199	1.352	1.504
25						1.123	1.290	1.456	1.619

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [0.53822(D^2H4)^{0.89584}]0.98$.

[4/] $Y = [0.00660(D^2H4)^{0.90328}]/79.6$.

Table 16.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem to 4-inch top for soft hardwoods by d.b.h. and height to 4-inch d.o.b. top

D.b.h. class (inches)	Height to 4-inch top (feet)[1/ 2/]								
	10	20	30	40	50	60	70	80	90
	Pounds[3/]								
5	64	118	169	218	266				
6	88	163	234	302	368	433			
7		214	308	397	484	570	653		
8		272	390	504	614	722	829	933	
9			481	621	757	891	1022	1151	1278
10			580	749	914	1074	1232	1388	1541
11			687	888	1082	1273	1460	1644	1826
12			802	1036	1264	1486	1704	1919	2131
13			925	1195	1457	1713	1965	2213	2457
14			1055	1363	1662	1955	2242	2525	2804
15				1541	1879	2210	2535	2854	3170
16				1728	2108	2479	2843	3202	3555
17				1925	2348	2761	3167	3566	3960
18				2131	2599	3057	3506	3948	4384
19				2346	2862	3365	3860	4347	4827
20					3135	3687	4229	4762	5288
21					3419	4021	4612	5194	5767
22					3714	4368	5010	5642	6265
23					4020	4727	5422	6106	6780
24						5099	5848	6586	7313
25						5483	6289	7082	7864
	Cords[4/]								
5	0.013	0.023	0.033	0.043	0.053				
6	0.017	0.032	0.046	0.060	0.073	0.086			
7		0.042	0.061	0.079	0.096	0.113	0.129		
8		0.054	0.077	0.100	0.121	0.143	0.164	0.184	
9			0.095	0.123	0.150	0.176	0.202	0.227	0.252
10			0.115	0.148	0.180	0.212	0.243	0.274	0.304
11			0.136	0.175	0.214	0.251	0.288	0.325	0.360
12			0.158	0.205	0.249	0.293	0.336	0.379	0.421
13			0.183	0.236	0.288	0.338	0.388	0.437	0.485
14			0.208	0.269	0.328	0.386	0.442	0.498	0.553
15				0.304	0.371	0.436	0.500	0.563	0.625
16				0.341	0.416	0.489	0.561	0.631	0.701
17				0.380	0.463	0.545	0.624	0.703	0.781
18				0.421	0.513	0.603	0.691	0.778	0.864
19				0.463	0.564	0.664	0.761	0.857	0.951
20					0.618	0.727	0.833	0.938	1.042
21					0.674	0.793	0.909	1.023	1.136
22					0.732	0.861	0.987	1.112	1.234
23					0.792	0.932	1.068	1.203	1.336
24						1.005	1.152	1.297	1.440
25						1.080	1.239	1.395	1.549

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [0.47816(D^2H4)^{0.88942}]0.98$.

[4/] $Y = [0.00745(D^2H4)^{0.88813}]/79.6$.

Table 17.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem plus crown for hard hardwoods by d.b.h. and total height

D.b.h. class (inches)	Total height (feet)[1/ 2/]								
	40	50	60	70	80	90	100	110	120
	Pounds[3/ 4/]								
5	122	155	188	221					
6	180	228	277	326	375				
7	250	316	384	452	520	589	659		
8	331	420	509	599	690	782	874		
9		539	653	769	886	1004	1122	1241	
10		673	817	961	1107	1255	1403	1552	
11		848	1040	1236	1436	1638	1844	2052	2262
12		1030	1264	1502	1745	1991	2241	2494	2750
13		1233	1512	1798	2088	2383	2682	2985	3290
14		1456	1786	2123	2466	2814	3167	3524	3886
15			2085	2478	2879	3285	3697	4114	4536
16			2410	2864	3327	3797	4273	4755	5242
17			2760	3281	3811	4350	4895	5447	6006
18			3138	3730	4333	4945	5565	6193	6827
19			3543	4211	4891	5582	6282	6991	7708
20				4725	5488	6263	7048	7843	8647
21				5271	6123	6987	7863	8750	9647
22				5851	6796	7755	8728	9713	10708
23				6464	7508	8569	9643	10731	11831
24				7112	8260	9427	10609	11806	13016
25				7793	9052	10331	11626	12938	14264
	Cords[5/ 6/]								
5	0.020	0.025	0.031	0.036					
6	0.030	0.038	0.046	0.054	0.062				
7	0.041	0.052	0.063	0.075	0.086	0.098	0.109		
8	0.055	0.069	0.084	0.099	0.115	0.130	0.146		
9		0.089	0.108	0.128	0.147	0.167	0.187	0.207	
10		0.112	0.136	0.160	0.185	0.209	0.234	0.260	
11		0.141	0.174	0.206	0.240	0.274	0.308	0.343	0.379
12		0.172	0.211	0.251	0.292	0.333	0.375	0.418	0.461
13		0.206	0.253	0.301	0.350	0.399	0.449	0.500	0.552
14		0.243	0.299	0.355	0.413	0.472	0.531	0.591	0.652
15			0.349	0.415	0.482	0.551	0.620	0.691	0.762
16			0.404	0.480	0.558	0.637	0.717	0.799	0.881
17			0.463	0.550	0.640	0.730	0.822	0.915	1.010
18			0.526	0.626	0.727	0.831	0.935	1.041	1.148
19			0.594	0.707	0.822	0.938	1.056	1.176	1.297
20				0.793	0.922	1.053	1.186	1.320	1.456
21				0.886	1.029	1.175	1.323	1.473	1.625
22				0.983	1.143	1.305	1.470	1.636	1.804
23				1.087	1.263	1.443	1.624	1.808	1.994
24				1.196	1.390	1.588	1.788	1.990	2.195
25				1.312	1.524	1.741	1.960	2.182	2.406

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] Trees 5-10 inches d.b.h. $Y = [0.08313(D^2Th)^{1.05899}]0.98.$

[4/] Trees > 10 inches d.b.h. $Y = [0.04964(D^2Th)^{1.12146}]0.98.$

[5/] Trees 5-10 inches d.b.h. $Y = [0.00100(D^2Th)^{1.06772}]/79.6.$

[6/] Trees > 10 inches d.b.h. $Y = [0.00062(D^2Th)^{1.12612}]/79.6.$

Table 18.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem plus crown for soft hardwoods by d.b.h. and total height

D.b.h. class (inches)	Total height (feet)[1/ 2/]								
	40	50	60	70	80	90	100	110	120
	Pounds[3/ 4/]								
5	100	126	154	181	209				
6	147	187	227	268	309				
7	205	260	316	373	431	489	547		
8	273	346	421	497	574	651	729	807	
9		446	542	640	738	838	938	1039	1141
10		559	680	802	926	1050	1176	1302	1430
11		699	854	1011	1170	1332	1495	1660	1826
12		846	1033	1223	1416	1612	1809	2009	2210
13		1008	1231	1458	1688	1921	2157	2394	2634
14		1186	1449	1716	1986	2260	2537	2817	3099
15			1686	1996	2311	2630	2952	3277	3606
16			1942	2300	2663	3030	3401	3776	4154
17			2218	2627	3041	3461	3885	4313	4745
18			2515	2978	3448	3923	4404	4889	5379
19			2831	3353	3882	4417	4958	5505	6056
20				3752	4344	4943	5549	6161	6778
21				4176	4835	5502	6176	6857	7544
22				4625	5355	6093	6840	7594	8354
23				5099	5903	6717	7540	8372	9210
24				5598	6481	7375	8278	9191	10111
25				6122	7088	8066	9054	10052	11059
	Cords[5/ 6/]								
5	0.020	0.025	0.031	0.036	0.042				
6	0.029	0.037	0.045	0.053	0.061				
7	0.041	0.052	0.063	0.074	0.085	0.097	0.108		
8	0.054	0.069	0.084	0.099	0.114	0.129	0.144	0.160	
9		0.088	0.108	0.127	0.146	0.166	0.186	0.206	0.226
10		0.111	0.135	0.159	0.183	0.208	0.233	0.258	0.283
11		0.137	0.168	0.199	0.230	0.261	0.293	0.326	0.358
12		0.166	0.203	0.240	0.278	0.316	0.355	0.394	0.433
13		0.198	0.242	0.286	0.331	0.377	0.423	0.469	0.516
14		0.233	0.284	0.337	0.390	0.443	0.497	0.552	0.607
15			0.331	0.391	0.453	0.515	0.578	0.642	0.706
16			0.381	0.451	0.522	0.593	0.666	0.739	0.813
17			0.435	0.515	0.596	0.678	0.760	0.844	0.928
18			0.493	0.583	0.675	0.768	0.862	0.956	1.052
19			0.555	0.656	0.760	0.864	0.970	1.076	1.184
20				0.734	0.850	0.967	1.085	1.204	1.324
21				0.817	0.946	1.076	1.207	1.340	1.473
22				0.905	1.047	1.191	1.336	1.483	1.631
23				0.997	1.154	1.312	1.473	1.635	1.798
24				1.094	1.266	1.440	1.616	1.794	1.973
25				1.197	1.385	1.575	1.767	1.962	2.157

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] Trees 5-10 inches d.b.h. $Y = [0.06160(D^2Th)^{1.07239}]0.98.$

[4/] Trees > 10 inches d.b.h. $Y = [0.05064(D^2Th)^{1.09701}]0.98.$

[5/] Trees 5-10 inches d.b.h. $Y = [0.00096(D^2Th)^{1.07149}]/79.6.$

[6/] Trees > 10 inches d.b.h. $Y = [0.00080(D^2Th)^{1.09368}]/79.6.$

Table 19.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem to 4-inch top for hard hardwoods by d.b.h. and total height

D.b.h. class (inches)	Total height (feet)[1/ 2/]								
	40	50	60	70	80	90	100	110	120
	Pounds[3/]								
5	122	155	188	221					
6	180	228	277	326	375				
7	250	316	384	452	520	589	659		
8	331	420	509	599	690	782	874		
9		539	653	769	886	1004	1122	1241	
10		673	817	961	1107	1255	1403	1552	
11		824	999	1176	1355	1535	1716	1899	2082
12		991	1201	1415	1629	1846	2064	2283	2503
13		1174	1423	1676	1930	2187	2445	2705	2966
14		1373	1665	1961	2258	2558	2860	3164	3470
15			1927	2269	2614	2961	3311	3662	4016
16			2210	2602	2997	3395	3795	4199	4604
17			2512	2958	3407	3860	4315	4774	5235
18			2836	3339	3846	4357	4871	5388	5908
19			3180	3744	4312	4885	5462	6042	6625
20				4173	4807	5446	6089	6735	7385
21				4628	5331	6039	6751	7468	8189
22				5107	5882	6664	7451	8242	9037
23				5611	6463	7322	8186	9055	9929
24				6140	7073	8012	8958	9910	10866
25				6695	7712	8736	9767	10804	11847
	Cords[4/]								
5	0.020	0.025	0.031	0.036					
6	0.030	0.038	0.046	0.054	0.062				
7	0.041	0.052	0.063	0.075	0.086	0.098	0.109		
8	0.055	0.069	0.084	0.099	0.155	0.130	0.146		
9		0.089	0.108	0.128	0.147	0.167	0.187	0.207	
10		0.122	0.136	0.160	0.185	0.209	0.234	0.260	
11		0.137	0.167	0.196	0.226	0.257	0.287	0.318	0.349
12		0.165	0.201	0.236	0.273	0.309	0.346	0.383	0.420
13		0.196	0.238	0.280	0.323	0.367	0.410	0.454	0.499
14		0.229	0.279	0.329	0.379	0.430	0.481	0.532	0.584
15			0.323	0.381	0.439	0.498	0.557	0.617	0.677
16			0.371	0.437	0.504	0.571	0.640	0.708	0.777
17			0.422	0.497	0.574	0.650	0.728	0.806	0.884
18			0.477	0.562	0.648	0.735	0.822	0.910	0.999
19			0.535	0.631	0.727	0.825	0.923	1.022	1.121
20				0.704	0.812	0.920	1.030	1.140	1.251
21				0.781	0.901	1.021	1.143	1.265	1.389
22				0.863	0.995	1.128	1.262	1.398	1.534
23				0.948	1.094	1.240	1.388	1.537	1.686
24				1.039	1.198	1.358	1.520	1.683	1.847
25				1.133	1.307	1.482	1.659	1.836	2.015

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [0.08313(D^2Th)^{1.05899}]0.98$.

[4/] $Y = [0.00100(D^2Th)^{1.06772}]/79.6$.

Table 20.--Predicted green weight of wood and bark and volume of wood in firewood ≥ 4 inches d.o.b. in the stem to 4-inch top for soft hardwoods by d.b.h. and total height

D.b.h. class (inches)	Total height (feet)[1/ 2/]								
	40	50	60	70	80	90	100	110	120
	Pounds[3/]								
5	100	126	154	181	209				
6	147	187	227	268	309				
7	205	260	316	373	431	489	547		
8	273	346	421	497	574	651	729	807	
9		446	542	640	738	838	938	1039	1141
10		559	680	802	926	1050	1176	1302	1430
11		686	834	984	1136	1288	1443	1598	1754
12		827	1005	1186	1369	1553	1739	1926	2114
13		982	1194	1408	1625	1844	2064	2286	2510
14		1151	1399	1651	1905	2161	2420	2680	2942
15			1622	1914	2209	2506	2806	3108	3412
16			1863	2198	2536	2878	3222	3569	3918
17			2122	2503	2889	3278	3670	4065	4462
18			2399	2830	3265	3705	4148	4595	5044
19			2694	3178	3667	4161	4658	5160	5664
20				3547	4093	4644	5200	5760	6323
21				3939	4545	5157	5774	6395	7020
22				4352	5022	5698	6379	7066	7757
23				4787	5524	6268	7018	7773	8533
24				5245	6052	6867	7688	8516	9349
25				5725	6606	7495	8392	9295	10204
	Cords[4/]								
5	0.020	0.025	0.031	0.036	0.042				
6	0.029	0.037	0.045	0.053	0.061				
7	0.041	0.052	0.063	0.074	0.085	0.097	0.108		
8	0.054	0.069	0.084	0.099	0.114	0.129	0.144	0.160	
9		0.088	0.108	0.127	0.146	0.166	0.186	0.206	0.226
10		0.111	0.135	0.159	0.183	0.208	0.233	0.258	0.283
11		0.136	0.165	0.195	0.225	0.255	0.286	0.316	0.347
12		0.164	0.199	0.235	0.271	0.308	0.344	0.381	0.419
13		0.195	0.236	0.279	0.322	0.365	0.409	0.453	0.497
14		0.228	0.277	0.327	0.377	0.428	0.479	0.531	0.583
15			0.321	0.379	0.437	0.496	0.555	0.615	0.675
16			0.369	0.435	0.502	0.570	0.638	0.706	0.775
17			0.420	0.496	0.572	0.649	0.726	0.804	0.883
18			0.475	0.560	0.646	0.733	0.821	0.909	0.998
19			0.533	0.629	0.726	0.823	0.922	1.021	1.121
20				0.702	0.810	0.919	1.029	1.140	1.251
21				0.780	0.899	1.020	1.142	1.265	1.389
22				0.861	0.994	1.127	1.262	1.398	1.534
23				0.947	1.093	1.240	1.388	1.538	1.688
24				1.038	1.197	1.359	1.521	1.684	1.849
25				1.133	1.307	1.483	1.660	1.838	2.018

[1/] Blocked-in area indicates range of data.

[2/] Includes 0.5-foot stump allowance.

[3/] $Y = [0.06160(D^2Th)^{1.07239}]0.98$.

[4/] $Y = [0.00096(D^2Th)^{1.07149}]/79.6$.

Table 21.--Factors for correcting single species bias in firewood weight tables

Species	Weight correction factor[1/]
	HARD HARDWOODS
Northern red oak	0.987
Southern red oak	1.039
Scarlet oak	1.026
Chestnut oak	1.053
White oak	.987
Water oak	1.026
Hickory	.960
	SOFT HARDWOODS
Yellow-poplar	.969
Sweetgum	1.108
Blackgum	1.015
Red maple	1.015
White ash	.938

[1/] To use correction factor, multiply the sum of the predicted firewood weights for a species by its correction factor.

*U.S. Government Printing Office: 1982-539-000/4001

Clark, Alexander, III.
Predicted weights and volumes of firewood in hardwood trees in the Southeast. Res. Pap. SE-226. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1982. 28 p.

Equations are presented for predicting the green weight of wood and bark and volume of wood in firewood ⩾ 4 inches d.o.b. in the total tree above stump, in the main stem to 4-inch top, and in topwood above the saw-log top. Equations predict weight and volume of firewood by d.b.h. and total height, d.b.h. and height to 4-inch top, d.b.h. and saw-log merchantable height, and d.b.h. alone. Tables developed from equations show weight in pounds and volume in cords of firewood in a tree and its components by d.b.h. and height classes.

KEYWORDS: moisture content, specific gravity, yield tables, biomass, equations.

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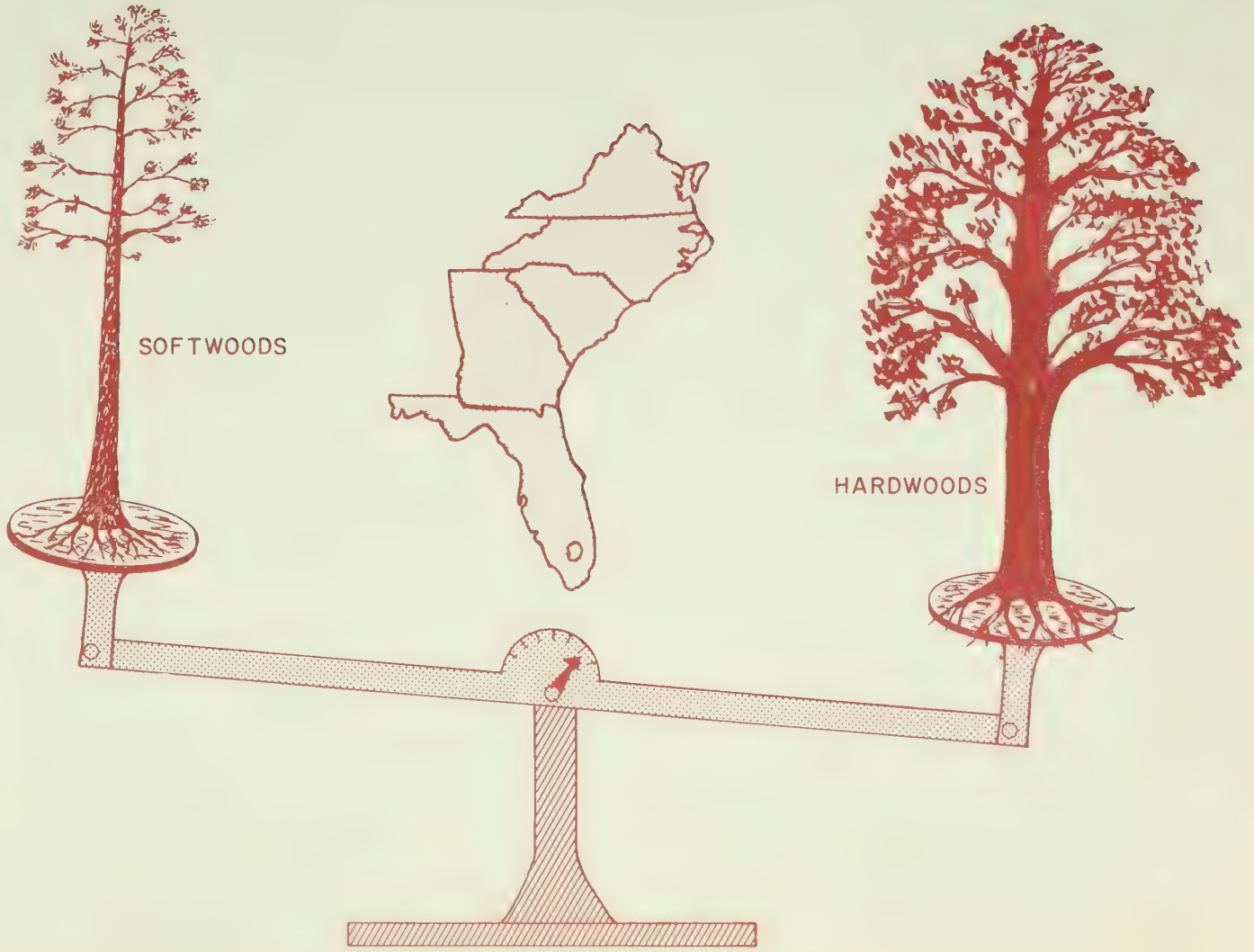
Southeastern Forest Experiment Station

Forest Service

BIOMASS IN SOUTHEASTERN FORESTS

Research Paper SE-227



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Biomass in Southeastern Forests

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ABSTRACT.- The 88.5 million acres of commercial forest land in the Southeast contain some 6.2 billion green tons of woody biomass. Distribution of this material is reported by State, tree size, and tree species. Relative amounts in various portions of typical trees are also reported for major species groups.

Keywords: Florida, Georgia, North Carolina, South Carolina, Virginia, forest inventory, fuelwood.

BIOMASS IN SOUTHEASTERN FORESTS

The purpose of any timber inventory is to describe the trees in a forest in terms that are meaningful to potential users. For the first 40 years after statewide Forest Surveys were started in the Southeast in 1933, primary interest was in sawtimber and cordwood volumes in the main stems of trees. These volumes to the prevailing merchantable top diameters were expressed in cubic feet, board feet, and cords meaningful units to the people who were using the wood. Two developments in recent years have created a need to express wood inventories in a new way: mobile tree chippers that can harvest the entire aboveground portions of trees and an energy shortage that makes all woody material valuable. Wood chips are traded by weight rather than volume, the fuel value of wood is more closely related to its weight than its volume, and other timber products are increasingly traded by weight. Thus, it is important that inventory results be expressed in terms of weight biomass.

This report represents the first effort to express the timber inventory of the Southeastern United States in terms of biomass. Numbers of trees, volumes, and weights are presented by State for the major timber species and species groups in the region. States included are Virginia, North and South Carolina, Georgia, and Florida. Regional tables show the proportions of cubic volume in various tree components.

The values reported are the best estimates that can be made at this time, but the techniques for estimating biomass can be greatly improved. In the first section of this report we describe the estimation techniques that were used. In the final section we describe practical changes that would improve the reliability and completeness of biomass data.

PROCEDURES

Much of the information in this report on numbers of trees of various sizes and on timber volumes is from the statewide forest inventories completed by the Renewable Resources Evaluation Unit of the Southeastern Forest Experiment Station. Inventory procedures are outlined in the Resource Bulletins that report the results of the most recent inventory in each State: 1972 for Georgia (Knight and McClure 1974), 1974 for North Carolina (Knight and McClure 1975), 1977 for Virginia (Knight and McClure 1978), 1978 for South Carolina (Knight and McClure 1979), and 1980 for Florida (report being prepared).

In the standard inventory the first step is to determine the acreage of forest land by classifying land use at thousands of photo points systemati-

cally spaced over each county. There are over 8 million such photo points in the Southeast. A subsample of these points is then examined on the ground to provide adjustments for changes since photos were taken and errors in photo interpretation. From the total acreage of forest land, areas that are withdrawn from timber utilization and areas incapable of producing crops of industrial wood are subtracted. What remains is termed "commercial forest land." The volumes and weights reported here apply solely to this commercial forest land.

Numbers and sizes of trees are tallied at 23,777 ground sample locations systematically distributed on commercial forest land. At each sample location, trees 5 inches d.b.h. and larger are measured at 3 to 10 points where variable-radius plots are defined by a prism with a basal-area factor of 37.5. Smaller treees are tallied on fixed-radius plots around the point centers.

Plot tallies and area figures permit estimation of the number of trees for each species and size class in the State. These numbers are converted to volumes through a series of equations based on detailed measurements of more than 35,000 trees from throughout the Southeast. Cost (1978) described the measurement of sample trees, as well as the system for developing the equations.

Biomass is defined here as the aboveground green weight of wood and bark in all live trees 1.0 inch d.b.h. and larger. In this paper, biomass estimates were made by using prediction equations developed by the Utilization of Southern Timber Research Unit of the Southeastern Forest Experiment Station in Athens, Georgia. For several years this unit has been developing equations for estimating total tree and tree component weights and volumes of the major southern tree species.

The procedures used for collecting and reporting detailed biomass data were outlined by Clark (1979) and Saucier (1979). Published reports from which appropriate equations were taken are by Clark and others (1980a, 1980b, 1980c); Clark and Schroeder (1977); McNab (In press); Phillips (1981); Saucier and Boyd (In press); and Taras (1980). Many other equations were from reports that are still being prepared for publication. These equations are the best available for estimating tree weight from d.b.h. and total height measurements. The database was compiled by felling, measuring, and weighing of total trees and tree components, and determining wood and bark proportions of more than 4,000 trees from 62 locations in the Southeast.

MAJOR FINDINGS

The 88.5 million acres of commercial forest land in the Southeast contain some 6.2 billion green tons of woody biomass. Among the five States, Georgia leads with 1.6 billion tons, and North Carolina is a close second with 1.5 billion tons. Florida ranks last with 0.8 billion tons. Table 1 shows bio-

State totals, of course, are dependent upon the acreage of commercial forest within the State as well as the concentration of material on these acres. In interpreting the totals, therefore, it is helpful to know how much commercial forest each State contains. These totals are:

State	Commercial forest
	Thousand acres
Georgia	24,839.0
North Carolina	19,544.8
Virginia	15,972.8
Florida	15,664.2
South Carolina	12,502.9
Total	88,523.7

Note that land withdrawn from timber production and land incapable of producing at least 20 cubic feet of wood per acre per year is excluded from these totals.

Average amounts of biomass per acre vary considerably by State. The Southeastern average of 70.7 green tons per acre represents a very wide range. The average for Florida is 55.2 tons and that for Virginia is 81.8 tons (table 2). Three factors obviously influence the biomass on a forest acre—age, stocking, and productivity of the site. A newly established stand may contain no woody material in stems over 1 inch in diameter at breast height, while a mature hardwood sawtimber stand on a good site may contain over 250 green tons of biomass per acre.

In Florida, where average biomass per acre is relatively low, more than half of the material is softwood. A large proportion of this softwood biomass is in pine plantations that are managed on short rotations. At the end of each rotation, biomass returns to near zero. In Virginia, on the other hand, more than three-fourths of the biomass is hardwood, and many of the hardwood stands are not managed for high timber production. Biomass has been allowed to accumulate in these stands for long periods, and it will continue to do so as long as hardwoods are underutilized.

MAJOR SPECIES

Loblolly pine is the most economically important timber species in the Southeastern United States. In Georgia, the Carolinas, and Virginia it is the most frequently planted species because of its rapid growth and suitability for construction lumber and paper pulp. The species' importance is reflected in its biomass of 0.9 billion tons (table 3). This is about twice the biomass of the

Southeast region, by State and species group	Biomass			Growing stock			Rough and rotten			Saplings
	Total	Bole	Top[2]	Total	Bole	Top	Total	Bole	Top	Total
	Million tons									
Florida:										
Softwoods	461.4	325.5	135.9	394.8	320.5	74.3	7.1	5.0	2.1	59.5
Hardwoods	402.4	267.6	134.8	225.0	179.8	45.2	110.6	87.8	22.7	66.7
Total	863.9	593.1	270.7	619.8	500.3	119.5	117.7	92.8	24.8	126.2
Georgia:										
Softwoods	762.7	554.3	208.4	656.0	546.2	109.8	10.7	8.1	2.5	96.0
Hardwoods	791.8	491.8	299.9	499.1	398.9	100.1	125.1	92.9	32.1	167.5
Total	1,554.6	1,046.2	508.3	1,155.1	945.1	209.9	135.8	101.0	34.7	263.6
North Carolina:										
Softwoods	510.2	384.4	125.8	450.3	379.2	71.0	10.1	5.1	5.0	49.7
Hardwoods	1,008.4	657.2	351.1	687.8	556.1	131.6	136.9	101.0	35.8	183.7
Total	1,518.6	1,041.7	476.9	1,138.1	935.4	202.6	147.1	106.2	40.8	233.4
South Carolina:										
Softwoods	433.1	337.9	95.2	389.9	328.8	61.0	11.4	9.1	2.3	31.8
Hardwoods	580.8	387.0	193.8	390.8	314.4	76.3	96.0	72.5	23.5	93.9
Total	1,014.0	724.9	289.0	780.8	643.3	137.4	107.5	81.6	25.8	125.6
Virginia:										
Softwoods	287.7	209.0	78.6	241.6	202.0	39.5	9.1	7.0	2.1	37.0
Hardwoods	1,019.2	691.0	328.2	695.8	561.4	134.4	173.4	130.0	43.8	150.0
Total	1,306.9	900.0	406.8	937.4	763.5	173.9	182.5	136.5	45.9	186.9
Total Southeast	6,258.1	4,306.1	1,951.9	4,631.3	3,787.7	843.6	690.7	518.4	172.3	936.0
Total Softwoods	2,455.1	1,811.1	643.9	2,132.6	1,776.7	355.6	48.4	34.3	14.0	274.0
Total Hardwoods	3,802.6	2,494.6	1,307.8	2,498.5	2,010.6	487.6	642.0	484.2	157.9	661.8

[1] Columns do not add because of rounding.
[2] Includes total sapling weight.

Table 2. Per acre green weight of aboveground tree biomass (excluding foliage) on commercial forest land in the Southeast, by State and species group[1]

Southeast region, by State and species group	Biomass			Growing stock			Rough and rotten			Saplings
	Total	Bole	Top[2]	Total	Bole	Top	Total	Bole	Top	Total
	Tons									
Florida:										
Softwoods	29.5	20.8	8.7	25.2	20.5	4.7	0.4	0.3	0.1	3.8
Hardwoods	25.7	17.1	8.6	14.4	11.5	2.9	7.1	5.6	1.4	4.3
Total	55.2	37.9	17.3	39.6	32.0	7.6	7.5	5.9	1.5	8.1
Georgia:										
Softwoods	30.7	22.3	8.4	26.4	22.0	4.4	.4	.3	.1	3.9
Hardwoods	31.9	19.8	12.1	20.1	16.1	4.0	5.0	3.7	1.3	6.7
Total	62.6	42.1	20.5	46.5	38.1	8.4	5.4	4.0	1.4	10.6
North Carolina:										
Softwoods	26.1	19.7	6.4	23.0	19.4	3.6	.5	.3	.2	2.5
Hardwoods	51.6	33.6	18.0	35.2	28.4	6.7	7.0	5.2	1.8	9.4
Total	77.7	53.3	24.4	58.2	47.8	10.3	7.5	5.5	2.1	11.9
South Carolina:										
Softwoods	34.6	27.0	7.6	31.2	26.3	4.9	.9	.7	.2	2.5
Hardwoods	46.4	31.0	15.5	31.3	25.2	6.1	7.7	5.8	1.9	7.5
Total	81.1	58.0	23.1	62.5	51.5	11.0	8.6	6.5	2.1	10.0
Virginia:										
Softwoods	18.0	13.1	4.9	15.1	12.6	2.5	.6	.4	.1	2.3
Hardwoods	63.8	43.3	20.5	43.6	35.1	8.4	10.8	8.1	2.7	9.4
Total	81.8	56.4	25.5	58.7	47.7	10.9	11.4	8.5	2.8	11.7
Average/acre:										
Softwoods	27.7	20.4	7.3	24.1	20.1	4.0	.5	.4	.2	3.1
Hardwoods	43.0	28.2	14.8	28.2	22.7	5.5	7.3	5.4	1.7	7.5
Total Southeast	70.7	48.6	22.1	52.3	42.8	9.5	7.8	5.8	1.9	10.6

[1] Columns do not add because of rounding.
[2] Includes total sapling weight.

Table 5.—Total green weight of aboveground softwood tree biomass (excluding foliage) on commercial forest land in the Southeast, by species and diameter class[1]

Species	All diameter classes	2	4	6	8	10	12	14	16	18	20	22–28	30+
	Million tons												
Southern pines:													
Loblolly	922.6	17.4	54.6	113.8	132.6	138.2	140.2	120.8	88.0	55.5	29.6	30.1	1.8
Longleaf	180.4	1.8	7.6	13.9	24.7	38.4	43.3	29.2	13.3	5.0	1.6	1.3	0
Pond	92.5	1.4	5.2	13.0	15.8	17.8	14.8	10.6	6.8	3.5	2.0	1.2	0
Shortleaf	255.0	6.8	20.2	38.4	55.2	55.6	40.6	22.0	9.4	4.2	1.5	1.0	0
Slash	460.8	15.4	64.2	95.8	93.8	68.2	52.8	33.6	19.8	9.0	4.4	3.4	.2
Virginia	211.0	10.7	32.4	45.4	48.8	39.0	21.0	9.0	2.9	1.0	.2	.1	0
Other	52.1	1.4	5.0	7.3	8.6	9.3	7.8	5.2	3.5	2.0	.8	.8	.1
Total	2,174.6	55.1	189.4	327.7	379.8	366.7	320.7	230.4	144.0	80.3	40.3	38.0	2.1
Other softwoods:													
Eastern white pine	40.2	.8	1.4	2.8	4.5	4.8	4.9	5.0	4.7	3.4	2.3	4.5	.8
Cypress	195.2	4.9	11.8	18.8	25.2	28.6	27.6	23.6	16.8	11.0	8.2	13.0	5.3
Other	45.3	4.1	6.4	7.9	5.6	5.2	3.4	3.4	2.2	1.6	1.6	2.4	1.4
Total	280.7	9.8	19.6	29.6	35.3	38.7	35.9	32.2	23.7	16.0	12.1	19.9	7.5
All species	2,455.4	65.0	209.0	357.4	415.1	405.4	356.7	262.6	167.7	96.4	52.5	58.0	9.6

[1] Columns do not add because of rounding.

most important timber species. Biomass of all southern pines in the Southeast is over 2.2 billion tons. Uses of species within this group are almost identical for trees of a given size. In addition to the southern pines, other important southeastern softwoods are eastern white pine in the Southern Appalachians, and cypress in the swamps. Cypress biomass in the region totals 195 million tons.

Forest survey crews in the Southeast tally information on some 50 different species of hardwoods. In this report, many of these species have been grouped to keep tables down to a manageable size and to reflect our lack of knowledge about relationships between volume and weight for many of the species. Volumes and weights are reported for 21 species and species groups. On the basis of wood texture, species are classed as "soft hardwoods" and "hard hardwoods."

Among soft hardwoods, the tupelos and blackgum together have the greatest biomass 406 million tons. Sweetgum is the single species with greatest biomass- 366 million tons. Biomass of the soft maples totals 317 million tons.

Oaks dominate in the hard hardwood group. All oaks together account for 1.5 billion green tons, almost one-quarter of the woody biomass in the Southeast. Eight individual species—black, chestnut, laurel, northern red, scarlet, southern red, water, and white oaks—are of considerable importance.

Hardwood exceeds softwood biomass in every Southeastern State except Florida, and hardwoods account for more than 60 percent of the region's woody biomass. Since southern pines are in greater demand than southern hardwoods, a continuation of current consumption patterns is likely to increase the proportion of hardwood in the Southeast's biomass inventory.

TYPES OF MATERIAL

People planning to exploit woody biomass as fuel would benefit by concentrating on materials that are currently unused by traditional forest industries. By doing so, competition for the available resource would be minimized, and fuelwood might be relatively cheap.

Major unutilized sources of wood include large quantities of logging residues, trees that do not meet merchantability standards, suppressed saplings in the understories of mature stands, and vast acreages of understocked stands needing regeneration but currently supporting insufficient volumes for profitable commercial logging.

The tables presented in this report show three essentially unutilized sources of wood and bark: tops, rough and rotten trees, and saplings. Tops are defined here as the portions of main stems and forks below 4 inches in diameter plus all limbs over ½ inch in diameter at the base in trees larger than 5 inches d.b.h. Biomass of saplings—trees 1 to 5 inches d.b.h.—is listed separately, but the material in saplings is similar in size to that in tops. Rough and rotten trees are those whose species or form makes them unsuitable for traditional commercial timber products.

In the Southeast, tops of growing-stock trees contain almost 0.8 billion tons of biomass, and rough and rotten trees contain another 0.7 billion tons. Saplings contain 1.0 billion tons (table 1). These three categories account for almost 40 percent of the region's biomass.

Tables 3 and 4 show biomass for the Southeast's major timber species by diameter class. Since species and size are the major determinants of utility, the values shown are rough indicators of the quantity of biomass present and of the surplus material in the inventory.

Table 5 shows how tree biomass is divided among major types of owners. Almost three-fourths of the biomass is controlled by private landowners other than forest industry. Only a little over one-tenth of the Southeast's biomass is on public land.

TREE COMPONENTS

Table 6 shows how biomass is distributed among components of individual trees of various sizes. Separate tables are presented for softwoods, hardwoods, and soft hardwoods.

These tables are presented primarily for those who wish to make their own biomass analyses. If number of trees of various sizes and species in an area can be estimated, these tables permit computation of the weight of wood and bark in saw logs, in stems to a 4-inch top, and in tops and limbs.

The distribution of wood between the saw-log portion and the upper-stem portion of trees is considerably different for hardwoods than for softwoods. In a 12-inch softwood, for example, 76 percent of the aboveground weight is in the saw-log portion and only 14 percent in tops and branches (table 6). In a 12-inch hard hardwood, on the other hand, only 54 percent of the weight is in the saw-log portion and 23 percent is in the upper stem. Part of this difference can be explained by the tendency of hardwoods to have large, spreading crowns and part by the difference in minimum saw-log diameters of softwoods and hardwoods. The minimum saw-log diameter outside bark is 7.0 inches for softwoods and 9.0 inches for hardwoods.

The relatively large amounts of biomass above the saw-log portions of hardwood trees are of considerable importance. In many hardwood logging operations, only saw logs are taken from the site. The remaining portions of the trees are left in the woods as logging residue, but under the proper economic conditions they might well be harvested for fuel. The most economical method is to harvest logging residue along with saw logs and then process it into fuelwood chips at a landing.

There is, however, a justified concern that the removal of all vegetation during harvest could result in excessive nutrient loss, increased erosion, and a general loss of site productivity. Research is needed to provide realistic guidelines for protecting site quality. Furthermore, certain cull trees containing cavities suitable for nesting sites are very valuable to wildlife and should not be arbitrarily destroyed.

Table 4.—Total green weight of aboveground hardwood tree biomass (excluding foliage) on commercial forest land in the Southeast, by species and diameter class[1]

Species	All diameter classes	2	4	6	8	10	12	14	16	18	20	22-28	30+
							Million tons						
Soft hardwoods:													
Sweetgum	366.1	26.8	41.1	44.9	48.0	49.0	46.0	36.7	27.2	17.2	11.2	15.3	2.4
Yellow-poplar	267.5	7.6	13.6	20.6	26.2	34.0	41.4	37.8	29.6	21.1	13.6	18.8	3.0
Tupelo and blackgum	406.3	29.8	36.0	34.0	42.0	48.7	52.3	48.2	36.5	26.2	16.6	28.1	7.8
Bay and magnolia	69.6	8.1	10.5	8.8	8.4	8.5	7.3	6.4	4.0	2.8	2.2	2.2	.6
Soft maples	317.5	37.7	47.8	41.9	39.8	38.8	31.1	25.0	18.6	12.8	8.7	12.9	2.2
Other species	115.4	9.1	12.7	12.2	14.0	13.0	13.2	11.0	9.1	6.2	4.2	8.2	2.4
Total	1,542.0	119.2	161.7	162.4	178.4	192.2	191.4	165.1	125.0	86.4	56.4	85.5	18.4
Oaks:													
Black	107.2	2.8	5.9	10.7	12.2	14.8	14.9	13.4	10.9	7.4	5.4	7.3	1.4
Chestnut	206.0	3.2	11.6	17.4	22.8	27.1	25.2	24.6	21.5	15.5	11.5	20.6	4.9
Laurel	129.1	5.8	8.4	9.4	11.3	13.1	12.3	12.2	10.3	8.9	7.8	21.1	8.4
Northern red	123.4	2.8	4.6	8.4	10.2	13.0	14.1	14.1	12.5	10.8	9.1	17.7	5.9
Scarlet	137.0	3.0	6.6	14.6	19.8	22.5	21.0	18.0	12.6	8.8	4.5	5.0	.4
Southern red	101.9	6.0	10.0	10.4	11.9	12.4	13.6	11.8	8.7	5.6	3.7	5.6	2.0
Water	154.8	13.4	17.2	21.8	19.6	18.0	15.8	12.5	10.0	7.8	5.2	9.8	3.4
White	304.2	8.4	18.0	28.9	33.7	41.8	42.1	38.0	31.0	20.8	14.6	22.4	4.6
Other	213.7	7.7	10.8	16.8	18.9	21.1	22.3	21.0	17.6	14.7	12.7	32.2	17.8
Scrub	65.8	14.3	15.4	14.0	9.7	5.8	3.8	1.5	.6	.4	.5	0	0
Total	1,543.2	67.4	108.7	152.6	170.0	189.8	185.2	167.2	136.0	100.7	74.6	141.7	49.2
Other hardwoods:													
Ash	86.0	7.9	10.0	12.2	11.5	10.8	9.5	8.1	5.8	4.2	2.4	3.0	.5
Hickory	210.2	12.4	17.6	20.5	23.9	27.0	26.5	25.4	18.9	14.7	8.0	12.6	2.5
Other hard hardwoods	273.2	42.1	46.6	25.8	26.8	27.2	26.4	21.4	15.3	13.6	8.7	16.2	3.1
Tropicals and misc.	123.0	28.9	39.4	24.9	13.9	7.3	4.0	1.9	1.1	.5	.4	.4	.1
Palms	24.6	0	.2	.1	2.0	8.4	8.6	3.2	1.4	.6	.2	.1	0
Total	717.0	91.3	113.6	83.6	78.2	80.7	75.0	60.0	42.6	33.6	19.8	32.2	6.3
All species	3,802.8	278.0	384.0	398.7	426.6	462.8	451.7	392.4	303.6	220.7	150.8	259.4	73.8

[1] Columns do not add because of rounding.

Table 5.—Total green weight of aboveground tree biomass (excluding foliage) on commercial forest land in the Southeast, by State and ownership[1]

State	Total, all ownerships	National Forest	Other public	Forest industry	Other private
			Million tons		
Florida	863.9	60.8	67.0	237.1	499.0
Georgia	1,554.6	74.8	54.6	261.0	1,164.3
North Carolina	1,518.6	102.4	40.6	136.8	1,238.6
South Carolina	1,014.0	60.9	43.4	172.2	737.4
Virginia	1,306.9	136.2	52.8	118.6	999.4
Total	6,258.1	435.2	258.3	925.8	4,638.8

[1] Columns do not add because of rounding.

Table 6.—Abovestump green weight distribution of wood and bark in tree components of softwoods, hard hardwoods, and soft hardwoods[1]

D.b.h. classes	Softwoods[2]			Hard hardwoods[4]			Soft hardwoods[5]		
	Saw log stem	Stem to 4-inch top	Tops and branches[3]	Saw log stem	Stem to 4-inch top	Tops and branches[3]	Saw log stem	Stem to 4-inch top	Tops and branches[3]
					Percent				
1		–	100			100	–	–	100
2	–	–	100			100	–	–	100
3	–	–	100	–	-	100	–	–	100
4	–	–	100	-	–	100	–	–	100
5	–	67	33		60	40	-	64	36
6	–	70	30		64	36	–	66	34
7	–	78	22	–	70	30	–	72	28
8	–	82	18	–	75	25	–	77	23
9	65	86	14	–	76	24	–	80	20
10	69	89	11	–	78	22	–	82	18
11	73	86	14	53	77	23	56	82	18
12	76	84	16	54	77	23	57	83	17
13	78	84	16	54	75	25	62	82	18
14	80	84	16	55	74	26	65	82	18
15	81	84	16	55	74	26	66	82	18
16	81	84	16	56	73	27	68	83	17
17	81	84	16	56	73	27	68	82	18
18	81	84	16	56	73	27	68	82	18
19	83	84	16	56	72	28	68	81	19
20	83	84	16	56	71	29	66	79	21

[1] Data based on over 4,000 sample trees.
[2] Softwoods: southern pines, white pine, hemlock, cypress, cedars, fir, and spruce.

Acceptable trees. Growing-stock trees of commercial species that meet specified standards of size and quality, but not qualifying as desirable trees.

Basal area. The area in square feet of the cross section at breast height of a single tree or of all the trees in a stand, usually expressed as square feet of basal area per acre.

Biomass.—The aboveground green weight of wood and bark in all live trees 1.0 inch d.b.h. and larger from the ground to the tip of the tree. All foliage is excluded, as is wood and bark in lateral limbs, secondary limbs, and twigs under 0.5 inch at their base.

Bole. Green weight of wood and bark between a 1-foot stump and a 4-inch top outside bark in trees 5.0 inches d.b.h. and larger. Merchantable volume.

Commercial forest land. Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization.

Commercial species. Tree species suitable for industrial wood products.

Desirable trees.—Growing-stock trees of commercial species having no serious defects in quality that limit present or prospective use for timber products, of relatively high vigor, and containing no pathogens that may result in death or serious deterioration before rotation age.

Diameter class.—A classification of trees based on diameter outside bark (d.o.b.), measured at breast height (4½ feet above the ground). D.b.h. is the common abbreviation for diameter at breast height. Two-inch diameter classes are commonly used in Forest Survey, with the even inch the approximate midpoint for a class. For example, the 6-inch class includes trees 5.00 through 6.99 inches d.b.h., inclusive.

Forest industry lands. Lands owned by companies or individuals operating wood-using plants.

Forest land. Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use.

Growing-stock volume. Net volume in cubic feet of growing-stock trees 5.0 inches d.b.h. and over from a 1-foot stump to a minimum 4.0-inch top diameter outside bark of the central stem, or to the point where the central stem breaks into limbs. (Net volume in primary forks is included.)

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Soft hardwoods.—Soft-textured hardwoods, such as boxelder, red and silver maple, hackberry, loblolly-bay, sweetgum, yellow-poplar, magnolia, sweetbay, water tupelo, blackgum, sycamore, cottonwood, black cherry, willow, basswood, and elm.

Hard hardwoods. Hard-textured hardwoods such as sugar maple, birch, hickory, dogwood, persimmon (forest grown), black locust, beech, ash, honeylocust, holly, black walnut, mulberry, and all commercial oaks.

Industrial wood.—All roundwood products except fuelwood.

Merchantable volume.—Volume of wood in cubic feet in trees of commercial species, measured from a 1-foot stump to a 4-inch top outside bark. Bole volume.

National Forest land. Federal lands which have been legally designated as National Forests or purchase units, and other lands under the administration of the Forest Service, including experimental areas and Bankhead-Jones Title III lands.

Noncommercial species.—Tree species of typically small size, poor form, or inferior quality which normally do not develop into trees suitable for industrial wood products.

Other Federal lands.—Federal lands other than National Forests, including lands administered by the Bureau of Land Management, Bureau of Indian Affairs, and other Federal agencies.

Other public lands.—Publicly owned lands other than National Forests.

Rotten trees. Live trees of commercial species that do not contain at least one 12-foot saw log, or two noncontiguous saw logs, each 8 feet or longer, now or prospectively, primarily because of rot or missing sections and with less than one-third of the gross tree volume in sound material.

Rough trees.—(a) Live trees of commercial species that do not contain at least one 12-foot saw log, or two noncontiguous saw logs, each 8 feet or longer, now or prospectively, primarily because of roughness, poor form, splits, and cracks, and with less than one-third of the gross tree volume in sound material; and (b) all live trees of noncommercial species.

Saplings. Live trees 1.0 inch to 5.0 inches in diameter at breast height.

Saw log.—A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight, and with a minimum diameter inside bark for softwoods of 6 inches (8 inches for hardwoods).

Saw-log portion. That part of the bole of sawtimber trees between the stump and the saw-log top.

Saw-log top. The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw-log top is 7.0 inches d.o.b. for softwoods and 9.0 inches d.o.b. for hardwoods.

Softwoods. Coniferous trees, usually evergreen, having needles or scale-like leaves.

Pines. Yellow pine species which include loblolly, longleaf, slash, pond, shortleaf, pitch, Virginia, and Table Mountain pine.

Other softwoods. Cypress, eastern redcedar, white cedar, eastern white pine, eastern hemlock, spruce, and fir.

Top.—The portion of the main stem and forks from a 4-inch outside bark diameter to the tips of the main stem and forks, plus all other limbs over 0.5 inch in diameter at their base.

Unproductive forest land.—Forest land incapable of producing 20 cubic feet per acre of industrial wood under natural conditions because of adverse site conditions.

Upper-stem portion.—That part of the main stem or fork of sawtimber trees above the saw-log top to a minimum top diameter 4.0 inches outside bark, or to the point where the main stem or fork breaks into limbs.

STATE TABLES

Detailed statistics on biomass in Southeastern States are shown in tables 7 through 31. There are five tables for each State. Values shown are numbers of trees, merchantable cubic volumes, total cubic volumes, merchantable green weights, and total green weights (excluding foliage). All values are shown by major timber species and by 2-inch diameter class.

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND TREES							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	122315	49626	26021	17056	8716	6689	5596	3030	2014	1228	599	563	13
LONGLEAF PINE	215537	47775	40413	35493	28573	29676	20947	9167	2798	613	163	159	0
POND PINE	55769	14851	15509	10673	6331	3802	2603	976	413	221	135	53	0
SHORTLEAF PINE	14002	3469	5014	2447	1093	685	616	467	110	54	26	21	0
SLASH PINE	1648988	576672	613619	360490	106101	61435	28126	13089	5920	2172	834	521	9
VIRGINIA PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER YELLOW PINES	214986	93742	60848	33947	14001	7631	2673	983	577	261	70	55	0
TOTAL YELLOW PINES	2471599	786135	762124	486100	224775	110110	60561	28284	11832	4549	1827	1372	22
OTHER SOFTWOODS:													
EASTERN WHITE PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPRESS	937191	436369	230479	124180	61571	48329	25515	13676	6375	3118	1658	1669	252
OTHER SOFTWOODS	30210	12697	7167	4331	2250	1416	1025	737	368	153	37	27	0
TOTAL OTHER SOFTWOODS	967401	449066	237646	128511	63821	49747	26540	14413	6743	3271	1695	1696	252
SOFT HARDWOODS:													
SWEETGUM	253600	154464	47169	20001	13965	7270	4512	2079	1437	603	432	316	38
YELLOW POPLAR	16643	6705	3486	1654	932	623	706	475	80	115	126	36	0
TUPELO AND BLACKGUM	852712	499998	174635	77479	38519	23771	15976	9641	5477	3034	1760	2121	279
BAY AND MAGNOLIA	672309	426778	139716	61767	22240	13707	7626	4097	2642	1176	672	453	33
SOFT MAPLES	286799	181863	47515	23659	13723	7584	5529	3191	1697	720	320	381	17
OTHER SPECIES	113036	74413	19416	8577	4613	2306	1453	1042	494	293	169	122	4
TOTAL SOFT HARDWOODS	2195296	1348241	432035	184037	94192	55261	35804	21325	11827	5841	3439	3429	371
OAKS:													
BLACK	221	221	0	0	0	0	0	0	0	0	0	0	0
CHESTNUT	0	0	0	0	0	0	0	0	0	0	0	0	0
LAUREL	372537	235507	64283	27075	15000	11460	6997	4502	2317	1619	1066	1705	327
NORTHERN RED	0	0	0	0	0	0	0	0	0	0	0	0	0
SCARLET	0	0	0	0	0	0	0	0	0	0	0	0	0
SOUTHERN RED	24796	14898	4675	2232	1590	902	377	255	278	76	52	64	0
WATER	247185	167597	37726	17959	10431	5816	3113	1953	1080	664	359	396	95
WHITE	7261	2735	2323	947	390	205	149	504	133	17	49	9	0
OTHER OAKS	333302	225775	47184	22100	10464	8394	5512	3023	2099	2151	1648	2673	679
SCRUB OAKS	808417	641050	114992	31276	12538	5461	2200	596	247	67	0	0	0
TOTAL OAKS	1793719	1287843	270589	101589	51007	32246	18348	11433	6954	4594	3174	4841	1101
OTHER HARDWOODS:													
ASH	354756	222921	77166	27602	12036	6802	3163	2169	1311	670	450	244	22
HICKORY	43039	23698	7691	3459	3161	1468	1271	924	534	331	123	168	11
OTHER HARD HARDWOODS	151738	116701	25453	9014	2051	1000	764	451	130	177	46	60	11
TROPICALS AND MISC. SPP.	345171	237937	67697	23430	9997	3272	1436	631	373	164	133	77	39
PALMS	68580	826	859	2146	13009	33188	24211	8673	3250	1266	287	65	0
TOTAL OTHER HARDWOODS	963084	602159	179056	61651	40654	45730	30845	12846	5598	2608	1039	614	82
ALL SPECIES	8411099	4467444	1851650	956086	494649	293102	172098	88103	42154	20663	11174	11946	1828

Table 8 Merchantable cubic volume of all live trees on commercial forest land, Florida, by species and diameter class, 1980

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
	THOUSAND CUBIC FEET												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	5926735	0	0	53174	491000	727744	1051886	995671	781810	633420	391020	500091	219889
LONGLEAF PINE	1367946	0	0	67712	176936	337736	390041	236593	91573	27682	8959	10512	0
POND PINE	167716	0	0	21146	29685	36053	41442	22900	14604	10330	7204	4352	0
SHORTLEAF PINE	54089	0	0	7000	6658	6660	11593	12390	3937	2480	1736	1429	0
SLASH PINE	3785742	0	0	836052	959762	677429	518430	344365	211998	99134	48833	39351	1368
VIRGINIA PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER YELLOW PINES	375411	0	0	91502	90451	65341	44647	23072	18775	12930	4378	4115	0
TOTAL YELLOW PINES	6307937	0	0	1126586	1311792	1216001	1111539	738687	419066	216098	110212	109766	3586
OTHER SOFTWOODS:													
EASTERN WHITE PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPRESS	2436499	0	0	317498	465012	469517	392034	292467	179030	114366	76792	103275	36506
OTHER SOFTWOODS	84207	0	0	9667	10536	14335	13855	15699	10793	6144	1530	1646	0
TOTAL OTHER SOFTWOODS	2520706	0	0	327165	465548	483852	405889	308166	189823	120512	78322	104923	36506
SOFT HARDWOODS:													
SWEETGUM	480353	0	0	40894	72559	74744	84384	77790	51147	24136	25335	24274	5090
YELLOW POPLAR	53101	0	0	3316	5458	6750	13480	6724	2587	4868	7125	2793	0
TUPELO AND BLACKGUM	1575055	0	0	179053	195210	219690	253536	222261	155485	115264	82840	124650	27466
BAY AND MAGNOLIA	738745	0	0	118623	117158	131191	117670	86148	59159	44280	31847	28135	4534
SOFT MAPLES	479394	0	0	55880	70782	72740	65388	70740	50883	27946	16529	26163	2343
OTHER SPECIES	158414	0	0	17776	24512	21325	22916	24205	17090	13158	6711	9726	995
TOTAL SOFT HARDWOODS	3485662	0	0	415542	485679	526440	577374	487668	336351	229652	170387	215941	40428
OAKS:													
BLACK	0	0	0	0	0	0	0	0	0	0	0	0	0
CHESTNUT	0	0	0	0	0	0	0	0	0	0	0	0	0
LAUREL	782646	0	0	63341	81348	106918	104960	93787	65510	60775	47274	116429	42304
NORTHERN RED	0	0	0	0	0	0	0	0	0	0	0	0	0
SCARLET	0	0	0	0	0	0	0	0	0	0	0	0	0
SOUTHERN RED	48230	0	0	4857	7181	8007	4866	5626	8001	2852	2672	4166	0
WATER	377461	0	0	45144	53970	56650	48889	45215	32930	29158	17249	32726	15530
WHITE	22904	0	0	1659	1842	1843	2791	6249	4613	691	2720	491	0
OTHER OAKS	853532	0	0	40675	45398	61862	70585	77267	60266	81468	75394	198931	121486
SCRUB OAKS	181572	0	0	55214	47170	35443	25071	10894	6133	1647	0	0	0
TOTAL OAKS	2266345	0	0	211090	236909	270728	257162	239038	197453	176591	145309	352745	179320
OTHER HARDWOODS:													
ASH	401203	0	0	61382	58834	64703	49257	51165	42372	27778	24544	19419	1749
HICKORY	133932	0	0	6510	15036	13828	20678	23810	16660	16238	7444	12016	1712
OTHER HARD HARDWOODS	64849	0	0	8314	9676	9397	12063	5776	4436	6981	2593	4490	1123
TROPICALS AND MISC. SPP.	164886	0	0	41809	40996	24668	17751	9607	8789	5009	6924	5093	4240
PALMS	1346936	0	0	7440	112357	461091	472763	172885	74852	32049	10245	3256	0
TOTAL OTHER HARDWOODS	2111806	0	0	125455	236899	573687	572512	263243	147109	88055	51750	44274	8824
ALL SPECIES	16748060	0	0	2205840	2736827	3070708	2924476	2037202	1289804	830908	555980	827651	268664

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
	- - -

Table 10. Merchantable green weight of all live trees on commercial forest land, Florida, by species and diameter class, 1980

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
	HUNDRED THOUSAND POUNDS												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	434640	0	0	25080	38413	53657	77215	72796	57001	46116	28434	36332	1594
LONGLEAF PINE	1057462	0	0	64673	137309	201464	306282	187142	72752	22251	7166	8423	0
POND PINE	134578	0	0	15578	21254	25378	29569	16402	10487	7428	5164	3136	0
SHORTLEAF PINE	39366	0	0	4679	4794	4815	8332	8892	2622	1776	1243	1023	0
SLASH PINE	2805349	0	0	68904	147705	215056	297844	265462	163933	76797	37892	30573	1061
VIRGINIA PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER YELLOW PINES	29366	0	0	0095	59559	57349	30983	16070	13314	9278	3173	2967	0
TOTAL YELLOW PINES	4839521	0	0	839809	1007024	918381	859225	566766	320309	163646	83092	82454	2675
OTHER SOFTWOODS:													
EASTERN WHITE PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPRESS	1611280	0	0	164003	264279	242457	271111	214593	136566	69543	61475	65132	32119
OTHER SOFTWOODS	65583	0	0	7013	7816	10359	10911	12500	8814	5040	1306	1422	0
TOTAL OTHER SOFTWOODS	1676863	0	0	171816	272097	302816	281622	227093	145382	94583	62781	66554	32119
SOFT HARDWOODS:													
SWEETGUM	385776	0	0	30577	52843	54623	62036	57553	38162	18176	19235	18709	4061
YELLOW POPLAR	37793	0	0	2256	3741	4679	9576	4812	1867	3549	5237	2074	0
TUPELO AND BLACKGUM	1043849	0	0	99624	116319	137163	162241	150070	109176	63949	62769	98840	23298
BAY AND MAGNOLIA	474051	0	0	65038	70463	82354	72326	57607	42239	32965	24695	22539	3825
SOFT MAPLES	359911	0	0	40906	53716	55597	62270	52926	38592	21364	12675	20074	1767
OTHER SPECIES	104299	0	0	11269	15730	13661	14293	15638	11544	9264	4803	7136	759
TOTAL SOFT HARDWOODS	2375679	0	0	249874	312814	348277	362742	338606	241580	169267	129414	169374	33730
OAKS:													
BLACK	0	0	0	0	0	0	0	0	0	0	0	0	0
CHESTNUT	0	0	0	0	0	0	0	0	0	0	0	0	0
LAUREL	634684	0	0	48536	65780	87967	84464	76463	53676	49885	38784	95070	34859
NORTHERN RED	0	0	0	0	0	0	0	0	0	0	0	0	0
SCARLET	0	0	0	0	0	0	0	0	0	0	0	0	0
SOUTHERN RED	39527	0	0	3304	5142	6161	4249	4872	7005	2524	2413	3657	0
WATER	310454	0	0	35988	43084	46143	40015	37584	27556	24488	14498	27405	12893
WHITE	19036	0	0	1250	1445	1495	2345	5241	3896	585	2328	421	0
OTHER OAKS	777977	0	0	32089	36515	50700	60173	67990	72351	74915	70233	190504	122507
SCRUB OAKS	193143	0	0	83472	50952	36684	24600	10287	5638	1510	0	0	0
TOTAL OAKS	1974791	0	0	164639	203718	229150	215646	202437	170122	153907	128256	317257	169459
OTHER HARDWOODS:													
ASH	258597	0	0	45214	40652	42305	31257	31529	25386	16379	14141	10755	941
HICKORY	110208	0	0	4747	11657	11276	16689	19599	13830	13737	6399	10502	1572
OTHER HARD HARDWOODS	54641	0	0	6262	8027	7903	9908	5035	3898	6186	2324	4209	1069
TROPICALS AND MISC. SPP.	107221	0	0	32080	28592	15999	10306	5449	4656	2552	3354	2411	1820
PALMS	471451	0	0	2604	39336	101387	165475	60512	26197	11216	3585	1139	0
TOTAL OTHER HARDWOODS	1002280	0	0	90907	128264	238870	233635	122124	73969	50070	29803	29016	5422
ALL SPECIES	11863993	0	0	1537045	1923917	2037494	1964270	1457026	951362	631473	433346	684655	243405

Table 11.—Total green weight of all live trees on commercial forest land, Florida, by species and diameter class, 1980

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
	HUNDRED THOUSAND POUNDS												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	527139	58[illegible]0	166[illegible]0	36032	44[illegible]7[illegible]	62c10	c8378	c252[illegible]	64276	51820	31891	40645	1779
LONGLEAF PINE	129756[illegible]	10[illegible]9[illegible]6	48027	89771	165[illegible]0[illegible]	381920	347593	210563	81444	24[illegible]3[illegible]	7998	9392	0
POND PINE	1[illegible]9101	1941	7934	20754	25c26	29697	34184	18021	11994	8479	5903	3568	0
SHORTLEAF PINE	53[illegible]44	729	4307	6[illegible]6[illegible]	5765	5594	9546	10102	3192	2002	1399	115[illegible]	0
SLASH PINE	4300701	12[illegible]012	62[illegible]e67	942[illegible]03	9[illegible]6347	596[illegible]82	452280	299015	1[illegible]3[illegible]52	[illegible]5[illegible]03	42230	34013	1197
VIRGINIA PINE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
OTHER YELLOW PINES	400523	19028	[illegible]5575	[illegible]9[illegible]54	73453	[illegible]7224	35581	18273	15029	10425	3557	3324	[illegible]
TOTAL YELLOW PINES	[illegible]745[illegible]6[illegible]	16[illegible]422	771[illegible]31[illegible]	11[illegible]4474	1220666	1[illegible]64327	[illegible]67[illegible]54	639307	359587	1[illegible]3[illegible]65	92978	[illegible]2092	2976
OTHER SOFTWOODS:													
EASTERN WHITE PINE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CYPRESS	2397234	6[illegible]8[illegible]9	175[illegible]2[illegible]	273762	367[illegible]4[illegible]	3[illegible]4768	347[illegible]54	271934	171427	111[illegible]6[illegible]	76030	105[illegible]13	42123
OTHER SOFTWOODS	[illegible]7[illegible]0[illegible]	163[illegible]	[illegible]926	11124	[illegible]637	12342	12526	14717	10316	[illegible]886	1539	1[illegible]47	0
TOTAL OTHER SOFTWOODS	2484534	7[illegible]527	181752	284[illegible]96	377085	397110	3[illegible]0380	2[illegible]6[illegible]51	181745	117246	77569	107460	42123
SOFT HARDWOODS:													
SWEETGUM	4[illegible]5[illegible]69	[illegible]1221	38527	45[illegible]0[illegible]	65574	[illegible]4704	71[illegible]50	[illegible]6[illegible]6[illegible]	43[illegible]8[illegible]	[illegible]0[illegible]93	21[illegible]61	2133[illegible]	4729
YELLOW POPLAR	47780	11[illegible]3	[illegible]e62	3158	4463	5393	10[illegible]94	5444	2104	4030	[illegible]896	2353	0
TUPELO AND BLACKGUM	1[illegible]3[illegible]85	[illegible]5734	164[illegible]79	148489	151[illegible]6[illegible]	171878	[illegible]0[illegible]03	1[illegible]4940	13[illegible]421	1[illegible]3702	77977	124652	30612
BAY AND MAGNOLIA	7[illegible]571[illegible]	64[illegible]67	111524	[illegible]6397	[illegible]9351	[illegible]9987	[illegible]6584	[illegible]8537	50021	38[illegible]76	29150	26817	4459
SOFT MAPLES	526099	3[illegible]9[illegible]6	[illegible]C76[illegible]	58332	[illegible]7540	[illegible]7[illegible]32	74[illegible]9[illegible]	[illegible]3231	46[illegible]42	25[illegible]9[illegible]	15040	23999	2143
OTHER SPECIES	15[illegible]48[illegible]	10[illegible]8	17021	16[illegible]74	19[illegible]03	16[illegible]43	16[illegible]29	18359	13435	10732	[illegible]5[illegible]4	8364	899
TOTAL SOFT HARDWOODS	35[illegible]8[illegible]32	[illegible]24039	365281	367[illegible]0[illegible]	39[illegible]62[illegible]	426237	4[illegible]1350	4[illegible]6657[illegible]	269709	203529	155508	207521	42842
OAKS:													
BLACK	3[illegible]	[illegible]6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHESTNUT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LAUREL	932[illegible]2	42977	[illegible]1[illegible]4	75592	[illegible]8511	114144	107973	97304	67[illegible]67	[illegible]2924	495[illegible]1	120[illegible]17	43618
NORTHERN RED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SCARLET	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SOUTHERN RED	[illegible]6965	24[illegible]5	3[illegible]7[illegible]	[illegible]293	7[illegible]15	7[illegible]63	5313	5997	8[illegible]45	3[illegible]78	2932	47[illegible]0	[illegible]
WATER	475139	31134	36553	[illegible]6971	59303	59423	[illegible]0815	47270	34611	30491	[illegible]2[illegible]7	34199	[illegible]6154
WHITE	26463	340	2[illegible]6[illegible]	1922	189[illegible]	1389	2919	6499	4[illegible]1[illegible]	721	2860	541	0
OTHER OAKS	107640[illegible]	33[illegible]6	[illegible]6740	[illegible]4403	50529	[illegible]6[illegible]4[illegible]	77502	[illegible]6294	91756	94789	[illegible]6596	239940	155543
SCRUB OAKS	491[illegible]5	10[illegible]539	112[illegible]32	1[illegible]0097	[illegible]9181	48161	31715	13[illegible]6[illegible]	7166	1946	[illegible]	[illegible]	[illegible]
TOTAL OAKS	3[illegible]59129	[illegible]19057	[illegible]52073	[illegible]94275	276429	[illegible]98120	276237	256[illegible]3[illegible]	214863	193949	162176	400197	215315
OTHER HARDWOODS:													
ASH	41[illegible]6[illegible]4	37517	59963	[illegible]5[illegible]26	50351	50083	36404	3645[illegible]	[illegible]930[illegible]	18754	16133	12[illegible]0[illegible]	1150
HICKORY	149192	[illegible]679	7924	7541	15356	14164	[illegible]0760	23868	16[illegible]4[illegible]	16574	7757	12[illegible]40	1[illegible]61
OTHER HARD HARDWOODS	11[illegible]7[illegible]	[illegible]1[illegible]38	[illegible]4[illegible]64	9541	10[illegible]9[illegible]	9975	12287	[illegible]17[illegible]	4729	7[illegible]49	2820	[illegible]321	1390
TROPICALS AND MISC. SPP.	[illegible]0[illegible]492	[illegible]9[illegible]3	[illegible]0144	49512	39143	[illegible]1113	13[illegible]4[illegible]	7143	[illegible]211	3422	4349	[illegible]081	2525
PALMS	49[illegible]34[illegible]	[illegible]8	434	[illegible]759	[illegible]11[illegible]6	[illegible]67747	171901	[illegible]3[illegible]3[illegible]	[illegible]7[illegible]6	[illegible]1[illegible]74	[illegible]797	[illegible]197	[illegible]
TOTAL OTHER HARDWOODS	1[illegible]2[illegible]065	[illegible][illegible]2195	[illegible]5[illegible]32[illegible]	[illegible]34[illegible]79	[illegible]56542	[illegible]63[illegible]82	[illegible]54996	137277	[illegible]4[illegible]43	58373	34856	34745	6946
ALL SPECIES	17279[illegible]2[illegible]	78[illegible]240	1743745	[illegible]266322	[illegible]42[illegible]351	2448[illegible]7[illegible]	[illegible]320[illegible]2[illegible]	1[illegible]26252	1130747	7[illegible]6462	[illegible]23087	842015	310202

Table 12. Number of all live trees on commercial forest land, Georgia, by species and diameter class, 1972

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
	THOUSAND TREES												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	2548602	1189422	606716	349546	154602	98446	58096	34206	15966	7052	2709	1796	51
LONGLEAF PINE	205304	52465	46684	32155	25245	21422	15602	7692	2556	719	250	112	0
POND PINE	66617	16467	18367	14313	6706	4926	3233	1453	651	329	93	77	0
SHORTLEAF PINE	1146177	544366	287474	160301	80667	41269	20676	7603	2325	793	209	91	3
SLASH PINE	1858673	787464	524122	303733	134987	57386	29067	13504	5399	1786	748	440	15
VIRGINIA PINE	355786	195954	63633	38926	21722	10260	3545	1269	369	96	10	0	0
OTHER YELLOW PINES	19041	9207	2957	2013	1792	1156	1173	639	327	157	45	66	7
TOTAL YELLOW PINES	6201103	2795365	1569953	930989	456121	234863	131792	66566	27795	10932	4064	2584	76
OTHER SOFTWOODS:													
EASTERN WHITE PINE	29936	14160	6159	3412	1746	1306	1023	536	680	302	283	309	16
CYPRESS	278916	162099	48184	27658	17620	10478	6650	3566	1615	668	322	364	66
OTHER SOFTWOODS	64695	46500	10726	2698	1265	894	303	129	79	32	24	30	13
TOTAL OTHER SOFTWOODS	373541	224759	65071	33768	20633	12680	7976	4231	2574	1002	629	703	115
SOFT HARDWOODS:													
SWEETGUM	1758042	1187205	332694	117183	55684	32136	16526	8958	4140	1725	963	830	56
YELLOW POPLAR	320431	181012	55005	31543	17732	12591	9742	5575	3685	1726	825	678	117
TUPELO AND BLACKGUM	1599717	1100637	239969	136612	63606	40620	23618	12787	6443	2852	1220	1219	134
BAY AND MAGNOLIA	301631	210660	48352	20384	10047	5772	3026	2029	685	349	178	105	24
SOFT MAPLES	981626	730959	147200	47333	25477	13985	7128	4426	2243	1389	713	697	76
OTHER SPECIES	494254	357186	83232	25522	13129	6521	3832	2352	1272	648	250	296	14
TOTAL SOFT HARDWOODS	5455701	3767679	906452	348577	185675	111625	63874	36127	18468	8689	4089	4025	421
OAKS:													
BLACK	130667	81408	22176	8276	6949	4370	3117	1995	1143	592	328	296	17
CHESTNUT	176015	93502	38776	15416	9615	7041	4524	3016	1721	1071	586	489	59
LAUREL	364729	239042	66737	23426	12821	7932	4583	3290	2257	1415	1077	1803	349
NORTHERN RED	80032	41138	15599	9663	4464	3583	2078	1180	798	671	391	412	55
SCARLET	104011	54053	17345	10127	8562	5547	3790	2202	1249	724	231	173	8
SOUTHERN RED	358534	220847	71452	31237	15734	9081	4650	2706	1294	641	461	361	68
WATER	676946	465160	124513	42564	19679	10516	6258	3487	2146	1153	567	767	96
WHITE	346096	187600	79696	32745	18340	11646	6966	4293	2694	1079	712	846	77
OTHER OAKS	364136	226479	66204	28489	17479	9791	6472	3616	2035	1068	946	1229	328
SCRUB OAKS	554304	433453	79975	23591	11128	3868	1476	503	136	133	29	6	6
TOTAL OAKS	3155470	2042702	582473	225534	124971	73375	43911	26290	14873	8547	5348	6384	1062
OTHER HARDWOODS:													
ASH	214063	143819	37657	12980	8861	4656	2935	1550	722	435	221	212	15
HICKORY	611617	431634	93093	39481	19313	12093	7108	4281	2263	1179	554	582	36
OTHER HARD HARDWOODS	1102257	958680	171072	34592	8847	3354	2372	1546	622	588	251	299	34
TROPICALS AND MISC. SPP.	856116	662210	137160	38124	11960	4055	1620	409	356	117	56	49	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2864053	2196343	438982	125177	48981	24158	14035	7786	3963	2319	1082	1142	85
ALL SPECIES	18049865	11026848	3562931	1634045	835781	456701	261588	141000	67673	31489	15212	14838	1759

Table 13. Merchantable cubic volume of all live trees on commercial forest land, Georgia, by species and diameter class, 1972

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND CUBIC FEET							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	6200867	0	0	834134	1041149	1059798	1075533	913085	567719	350099	174399	156386	8565
LONGLEAF PINE	1254681	0	0	93445	176446	266401	324906	218097	96279	35432	14483	9392	0
POND PINE	278925	0	0	33676	38932	51522	59814	37664	30455	14949	5508	6323	0
SHORTLEAF PINE	2042646	0	0	365785	476308	460584	388632	263313	86236	39523	14024	7608	427
SLASH PINE	3797890	0	0	786335	848525	751603	615885	394180	217337	95475	50268	36159	2763
VIRGINIA PINE	463810	0	0	109971	132986	114197	57509	30626	12744	4904	673	0	0
OTHER YELLOW PINES	98926	0	0	4659	10514	12439	22934	17000	12947	7612	3252	6030	1339
TOTAL YELLOW PINES	14137939	0	0	2222207	2724860	2735944	2545413	1814165	1043717	547994	262627	221698	13114
OTHER SOFTWOODS:													
EASTERN WHITE PINE	155301	0	0	9454	9467	13769	17692	13484	24155	14821	18309	31785	2365
CYPRESS	663602	0	0	64816	108234	114084	117942	90695	62654	29792	17377	24289	13919
OTHER SOFTWOODS	35673	0	0	5206	5560	7753	4173	2072	2076	1561	1645	3194	2427
TOTAL OTHER SOFTWOODS	854776	0	0	99476	123267	135606	139807	106251	88685	46174	37331	59266	18711
SOFT HARDWOODS:													
SWEETGUM	1819355	0	0	245093	310630	351225	307192	240146	149955	77329	56052	73267	8266
YELLOW POPLAR	961790	0	0	52671	106026	140757	175153	144499	126007	74150	40260	68628	17437
TUPELO AND BLACKGUM	2151805	0	0	262621	356466	407052	363669	297518	189583	104950	48632	86511	14601
BAY AND MAGNOLIA	321543	0	0	55882	60777	57054	51197	45923	19966	12160	7560	7704	3318
SOFT MAPLES	794940	0	0	120506	137390	135153	107533	93447	60652	50996	30065	50913	8283
OTHER SPECIES	423795	0	0	57029	70014	65218	62795	56662	42357	28009	14404	25107	2000
TOTAL SOFT HARDWOODS	6491228	0	0	824004	1041507	1156459	1067539	878395	588522	347594	202973	312330	53905
OAKS:													
BLACK	263291	0	0	19131	37155	43848	42367	43303	33669	24494	16861	19961	2502
CHESTNUT	451969	0	0	35262	52373	68903	68905	65590	52735	40529	27768	33473	6434
LAUREL	779340	0	0	57257	77016	81924	74636	76022	67311	56593	54398	168916	64480
NORTHERN RED	262127	0	0	27608	26603	37389	35978	29892	28013	29553	22195	35386	9510
SCARLET	335336	0	0	27074	48036	56625	60665	51057	38721	27334	12709	12138	765
SOUTHERN RED	464742	0	0	67870	75687	81958	69051	56313	36660	23361	20876	26114	10646
WATER	748818	0	0	115247	114956	108664	106762	77332	67550	45587	29560	66507	16713
WHITE	776653	0	0	83110	104451	126662	117156	107749	69826	45614	39752	69876	12462
OTHER OAKS	767311	0	0	64736	87934	85896	68782	76766	57945	36971	42615	103674	61768
SCRUB OAKS	137481	0	0	37830	42226	29114	16393	7631	2986	3515	937	237	650
TOTAL OAKS	4967075	0	0	535127	666636	717183	676655	592457	489422	333538	267611	536482	185970
OTHER HARDWOODS:													
ASH	292674	0	0	32211	51636	48991	49115	37044	23729	17274	12126	18204	2544
HICKORY	761000	0	0	86491	103376	119626	120297	105479	78115	54732	33165	53683	5836
OTHER HARD HARDWOODS	286559	0	0	54019	41668	32161	39784	34608	19327	21032	11308	19189	4263
TROPICALS AND MISC. SPP.	198056	0	0	76181	50315	30575	18566	6752	7675	3286	1848	2658	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	1538491	0	0	258902	247195	231353	226764	183683	128846	96324	58447	94134	12643
ALL SPECIES	27991509	0	0	3945716	4863459	4976545	4676176	3575151	2305392	1371624	828989	1224112	284343

Table 14 Total cubic volume of all live trees on commercial forest land, Georgia, by species and diameter class, 1972

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
							THOUSAND CUBIC FEET						
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	8315795	210104	699850	1194483	1270961	1236637	1231423	1035507	663005	393545	195609	175097	9574
LONGLEAF PINE	1562174	16750	83659	130150	212430	330717	368936	245502	107849	39582	16148	10451	0
POND PINE	350912	3020	17696	45156	46886	60299	69103	43255	34844	17088	6364	7199	0
SHORTLEAF PINE	2805635	87902	259127	504022	575405	535627	445291	231113	97545	44588	15789	8547	479
SLASH PINE	5641480	226983	812241	1109322	1028852	869489	700523	444307	243733	106709	55998	40237	3086
VIRGINIA PINE	763427	54519	141125	145409	160280	134007	66638	35487	14594	5600	768	0	0
OTHER YELLOW PINES	123343	2832	5615	6676	12566	14483	26391	19415	14769	8644	3677	6778	1497
TOTAL YELLOW PINES	19562766	607110	2019313	3135216	3307382	3181459	2908305	2054586	1176339	615756	294353	248309	14636
OTHER SOFTWOODS:													
EASTERN WHITE PINE	188513	1682	4744	12393	11571	16214	20649	15660	27962	17121	21130	36644	2743
CYPRESS	989706	29692	61680	144269	150570	150291	151773	114657	78212	36987	21660	30704	19005
OTHER SOFTWOODS	63749	8961	10359	7947	7102	9409	4998	2456	2418	1803	1865	3652	2759
TOTAL OTHER SOFTWOODS	1241962	40335	76983	164609	169243	175914	177420	132773	108592	55911	44675	71000	24507
SOFT HARDWOODS:													
SWEETGUM	2775935	213268	343209	364711	387351	416616	356853	276223	171745	88606	63818	83698	9637
YELLOW POPLAR	1262410	41603	79574	111331	126583	162606	199617	163861	142676	83802	52325	78252	20180
TUPELO AND BLACKGUM	3314861	261231	294819	393265	463826	509175	474130	365355	232653	129638	60680	110113	19976
BAY AND MAGNOLIA	507519	35473	65666	82537	76935	69869	61397	54993	23771	14542	9002	9333	4001
SOFT MAPLES	1405608	173887	231658	173776	174893	165644	130467	112867	73043	61317	36384	61377	10293
OTHER SPECIES	701117	78224	101844	82001	87596	78421	74763	67382	49550	32684	16853	29451	2346
TOTAL SOFT HARDWOODS	9967450	803686	1116770	1207623	1317186	1402331	1297227	1040681	693438	410589	239062	372424	66433
OAKS:													
BLACK	411600	18404	28796	29451	49306	55900	53569	54416	42042	30355	21048	25403	3110
CHESTNUT	638470	18543	43481	51107	68298	86905	86809	81925	65472	50639	34717	42293	8281
LAUREL	1158205	53791	83818	89532	103637	106294	95168	97715	85634	72001	69125	216647	84843
NORTHERN RED	389427	10330	19844	38120	34333	47262	45036	37501	34901	37031	27988	44910	12171
SCARLET	466772	16356	20099	38642	62536	72054	76118	63975	48761	35325	16022	15727	1155
SOUTHERN RED	756678	55976	84024	111598	103563	105286	81343	69612	45282	28682	26070	32120	13122
WATER	1250868	106429	151125	181194	154831	140190	135347	97801	84610	57286	36837	83983	21235
WHITE	1127879	41542	87126	123188	137424	160587	146939	134009	86929	56895	49525	87850	15865
OTHER OAKS	1031389	42067	67755	102013	118217	110807	113261	96778	72724	46422	53528	130095	77722
SCRUB OAKS	344189	62651	81853	59025	57138	32693	25875	12749	4391	5498	1209	297	810
TOTAL OAKS	7575677	426089	667921	823870	889285	917978	859465	746481	570746	420134	336069	679325	238314
OTHER HARDWOODS:													
ASH	417819	29714	34667	46670	63702	57936	57302	42687	27349	19854	13930	20831	2977
HICKORY	1185616	87448	118279	138752	137075	150642	148043	129255	95485	66527	40942	65671	7497
OTHER HARD HARDWOODS	781011	217147	209712	77016	50243	40171	48654	43285	24126	26507	14466	24303	5379
TROPICALS AND MISC. SPP.	581450	136510	169650	112503	68587	40252	24541	8880	10067	4279	2452	3729	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2965896	470819	532308	374941	319607	289001	278540	224307	157029	117167	71790	114534	15853
ALL SPECIES	41313751	2348039	4413295	5706261	6002703	5966683	5520957	4198828	2706144	1619557	985949	1485592	359743

Table 15. Merchantable green weight of all live trees on commercial forest land, Georgia, by species and diameter class, 1972

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
	HUNDRED THOUSAND POUNDS												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	4582169	0	0	631217	773860	787175	790926	668254	428927	255051	120888	113657	6214
LONGLEAF PINE	975971	0	0	67522	136337	221320	254661	172297	76482	28249	11572	7531	0
POND PINE	199982	0	0	24080	27850	36444	42667	26964	21659	10741	4022	4555	0
SHORTLEAF PINE	1427159	0	0	230750	328082	332641	279741	145987	61634	28324	10044	5446	305
SLASH PINE	2904452	0	0	536690	659164	571020	472419	303796	168004	73963	38944	28082	2168
VIRGINIA PINE	358046	0	0	93133	100627	84941	42715	22856	9445	3631	498	0	0
OTHER YELLOW PINES	68800	0	0	3319	7464	8348	15643	11644	9031	5329	2314	4335	973
TOTAL YELLOW PINES	10512579	0	0	1637711	2033584	2041689	1898972	1352600	775587	465288	194282	163606	9660
OTHER SOFTWOODS:													
EASTERN WHITE PINE	102683	0	0	6495	6342	9147	11985	9126	16204	9822	11949	20148	1465
CYPRESS	444173	0	0	42751	62779	71034	82656	67341	48154	23586	14005	20088	12377
OTHER SOFTWOODS	27220	0	0	4267	4322	5829	3112	1556	1580	1196	1246	2360	1752
TOTAL OTHER SOFTWOODS	574076	0	0	53513	73443	86010	97153	78023	65938	34606	27200	42596	15594
SOFT HARDWOODS:													
SWEETGUM	1350614	0	0	168625	226536	256427	225797	177482	111779	58165	42606	56461	6555
YELLOW POPLAR	697131	0	0	56346	72516	97491	123964	103500	91065	53999	33956	51039	13253
TUPELO AND BLACKGUM	1380033	0	0	144416	211259	253993	245439	199612	132431	76030	36122	67934	12595
BAY AND MAGNOLIA	201239	0	0	30457	35754	34493	31684	30696	14200	8984	5832	6162	2777
SOFT MAPLES	596605	0	0	87682	104101	103415	78079	59782	45966	38962	23050	39056	6311
OTHER SPECIES	279444	0	0	36670	44747	42523	38918	37101	28919	19647	10314	18780	1628
TOTAL SOFT HARDWOODS	4505066	0	0	544606	694915	768339	743881	618573	424362	255987	151859	239431	43119
OAKS:													
BLACK	254445	0	0	18380	34126	39851	38698	38452	29586	21330	14619	17252	2148
CHESTNUT	356019	0	0	26987	39966	53571	53002	51525	40173	32797	22735	27621	5440
LAUREL	631272	0	0	42985	62254	67431	60127	62705	55211	46459	44600	137732	51768
NORTHERN RED	231705	0	0	21012	21566	31109	29512	24681	23206	24551	18489	29569	8008
SCARLET	294696	0	0	23688	42210	50371	54359	44644	33644	27594	10919	10399	670
SOUTHERN RED	378053	0	0	44943	54021	62341	56435	48651	32016	20676	18752	24206	10608
WATER	613662	0	0	91174	93423	88550	87396	64121	56477	38265	24789	55782	13885
WHITE	640046	0	0	63426	82164	102655	98154	90486	58927	38729	33982	60459	11060
OTHER OAKS	602656	0	0	47031	69815	71466	74695	66195	50713	32924	38600	96883	60534
SCRUB OAKS	146511	0	0	43927	45619	26128	16049	7264	2746	3192	840	210	534
TOTAL OAKS	4150067	0	0	423555	545166	593473	568427	498926	384706	282517	228325	460315	164655
OTHER HARDWOODS:													
ASH	168217	0	0	23783	35611	32640	31107	22822	14234	10198	6970	10125	1362
HICKORY	617102	0	0	63063	79820	96948	98416	86094	64922	46183	26404	47258	5400
OTHER HARD HARDWOODS	237274	0	0	48139	33725	26792	32782	29298	16692	18285	10037	17486	4038
TROPICALS AND MISC. SPP.	140232	0	0	59776	39524	20128	12186	4246	4277	1746	930	1417	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	1162825	0	0	194761	188080	175908	174487	143060	100130	76412	46341	76286	10760
ALL SPECIES	20924613	0	0	2854140	3531788	3665619	3482920	2690582	1750725	1054810	648007	982234	243768

Table 16 — Total green weight of all live trees on commercial forest land, Georgia, by species and diameter class, 1972

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						HUNDRED THOUSAND POUNDS							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	6076214	150178	447560	904654	944696	918566	905578	757687	483672	286694	142323	127260	6944
LONGLEAF PINE	1206502	12233	59277	93670	164109	255567	269179	193956	85670	31553	12905	8383	0
POND PINE	250537	2165	11454	33403	33546	42651	49293	30975	25008	12277	4580	5185	0
SHORTLEAF PINE	1964561	70431	168224	316769	396220	386969	320358	165933	69947	31943	11306	6119	342
SLASH PINE	4257709	166032	577116	826442	799167	661061	537321	342395	168414	82671	43431	31255	2404
VIRGINIA PINE	579571	43464	100109	123439	121561	99669	49485	26310	10816	4148	568	0	0
OTHER YELLOW PINES	85928	2070	3974	4561	8924	9724	18231	13526	10301	6049	2615	4871	1086
TOTAL YELLOW PINES	14421022	446573	1367714	2302936	2468223	2374205	2169445	1530982	874036	455335	217728	183073	10776
OTHER SOFTWOODS:													
EASTERN WHITE PINE	124613	1243	3120	8526	7749	10773	13990	10600	18757	11344	13789	23230	1693
CYPRESS	661492	22669	45753	72376	87355	93484	105540	85117	60109	29299	17460	25410	16920
OTHER SOFTWOODS	48539	6845	7699	6513	5515	7061	3725	1641	1840	1380	1429	2695	1993
TOTAL OTHER SOFTWOODS	834644	30757	56572	87409	100619	111318	123255	97556	80706	42023	32678	51338	20611
SOFT HARDWOODS:													
SWEETGUM	2109388	175866	263186	261928	282327	304151	262307	204166	128032	66646	48483	64646	7646
YELLOW POPLAR	894281	30066	54581	75891	86569	112626	141260	117372	103103	61036	38404	58035	15334
TUPELO AND BLACKGUM	2207585	209734	235483	215602	274751	317662	303192	245358	162593	93971	45115	86737	17267
BAY AND MAGNOLIA	323601	25832	45112	44832	45239	42224	37975	36976	16896	10746	6946	7471	3352
SOFT MAPLES	1045490	130093	165534	126623	132484	126734	94734	84273	55354	46843	27890	47081	7847
OTHER SPECIES	478114	59550	75400	52815	55978	51117	46327	43974	33630	23134	12066	22010	1913
TOTAL SOFT HARDWOODS	7058459	631141	859298	797691	877348	954516	885795	732119	499808	302378	178904	285982	53479
OAKS:													
BLACK	371706	17854	25685	28354	45294	50606	48910	48316	36960	26434	18250	21971	2670
CHESTNUT	508762	16873	38076	39116	52103	67573	66790	64358	52360	40982	28409	35125	6997
LAUREL	953170	52228	75503	67014	83759	87491	76653	79755	70236	59108	56669	176638	68116
NORTHERN RED	322639	9998	17673	28991	27626	39325	36935	30964	28913	30760	23305	37511	10238
SCARLET	412046	15722	18196	33617	54949	63866	68203	56193	42375	30497	13765	13476	987
SOUTHERN RED	619457	54135	75947	73730	73688	80069	70561	60143	39532	25390	23416	29768	13078
WATER	1052596	103366	136357	143140	125819	114236	110768	81069	70736	48080	30953	70430	17642
WHITE	930228	36064	72256	93960	108082	130134	123112	112538	73356	48309	42336	76001	14060
OTHER OAKS	887695	39051	58735	74102	93642	92199	95291	83450	63648	41343	48484	121381	76169
SCRUB OAKS	364359	69666	81651	68662	61745	34009	25421	12155	4048	4988	1085	263	666
TOTAL OAKS	6422656	414957	603479	650886	727107	759710	722644	628941	482164	355891	286672	582564	210643
OTHER HARDWOODS:													
ASH	280846	24253	28263	34529	43940	37887	36297	26420	16410	11719	8004	11579	1545
HICKORY	975735	80884	103569	101054	105803	122038	121105	106233	79349	56126	35056	57577	6941
OTHER HARD HARDWOODS	652552	182969	175810	57975	40518	33455	41134	36676	20653	23062	12847	22152	5101
TROPICALS AND MISC. SPP.	446109	114263	135787	88415	48458	26502	16124	5583	5615	2283	1233	1846	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2355242	402369	443429	281973	238719	219882	214660	174912	122227	93190	57140	93154	13587
ALL SPECIES	31092225	1925797	3347492	4120897	4412016	4419631	4115799	3164512	2058935	1248817	773122	1196111	309096

Table 17.—Number of all live trees on commercial forest land, North Carolina, by species and diameter class, 1974

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND TREES							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	1531607	703923	364826	167744	110648	65157	44014	27500	15488	7343	2952	2049	63
LONGLEAF PINE	92620	25964	17976	16431	13041	8763	6028	2813	1064	397	98	51	0
POND PINE	433546	169290	110869	70675	40305	24306	9768	5094	2126	721	308	84	0
SHORTLEAF PINE	510335	170937	134034	67319	60070	35251	14601	5660	1628	567	174	94	0
SLASH PINE	38284	17131	12617	6745	1683	96	0	0	10	0	0	0	0
VIRGINIA PINE	685666	343950	167909	89020	49471	23751	8090	2603	656	169	41	6	0
OTHER YELLOW PINES	53306	13425	12311	10202	7988	5001	2381	1113	577	166	105	39	0
TOTAL YELLOW PINES	3345366	1444520	820536	468136	283206	162327	84882	44783	21549	9363	3678	2323	63
OTHER SOFTWOODS:													
EASTERN WHITE PINE	112126	63979	19664	7477	8113	4441	2797	2101	1462	979	441	563	109
CYPRESS	38013	13121	6382	4407	3405	3507	2602	1750	1017	678	435	600	109
OTHER SOFTWOODS	305714	209672	56344	20441	8363	5316	2056	1601	711	303	421	351	133
TOTAL OTHER SOFTWOODS	455853	286772	82390	32325	19881	13264	7457	5452	3190	1960	1297	1514	351
SOFT HARDWOODS:													
SWEETGUM	1500676	1070149	247061	65120	44841	23468	13430	7407	4774	2299	1034	1024	69
YELLOW POPLAR	544793	277790	107680	53622	36448	25353	18415	11953	6320	3520	1673	1723	96
TUPELO AND BLACKGUM	1033095	705823	152162	64222	42046	25294	16639	11360	6702	3972	2089	2330	456
BAY AND MAGNOLIA	412445	354265	41906	8695	3846	1608	946	709	263	91	66	43	5
SOFT MAPLES	2155064	1607520	327182	108689	50641	27598	15267	8407	4433	2478	1280	1442	127
OTHER SPECIES	434885	303111	60255	31543	18719	9049	5631	3039	1768	768	428	526	48
TOTAL SOFT HARDWOODS	6080958	4318658	936446	351891	196543	112370	70328	42875	24260	13128	6570	7088	801
OAKS:													
BLACK	129498	58987	28216	16501	8971	6562	4403	2272	1606	842	461	595	82
CHESTNUT	214368	79346	53043	28135	18409	13078	7854	5621	3539	1860	1257	1807	219
LAUREL	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHERN RED	127934	59030	26300	13775	8722	6260	4407	2958	2254	1388	1125	1440	275
SCARLET	151262	49271	34518	23686	15703	11463	7018	4535	2332	1487	641	593	13
SOUTHERN RED	207422	115038	46543	18683	11503	6063	4413	2504	1334	710	288	301	42
WATER	423247	293508	69898	29809	12941	7126	4235	2390	1306	857	420	627	130
WHITE	495331	256670	99931	53724	29091	21125	13653	7935	5111	2810	1418	1693	170
OTHER OAKS	304636	189460	49686	27450	14871	9816	5417	3154	2013	1050	548	982	169
SCRUB OAKS	306644	245554	39759	13435	5159	1937	648	99	45	8	0	0	0
TOTAL OAKS	2360342	1346884	447894	225200	125370	83430	52046	31668	19540	11012	6158	8038	1100
OTHER HARDWOODS:													
ASH	358501	250483	60560	21997	12037	5771	3342	1967	1144	684	243	253	20
HICKORY	411421	263942	66023	30669	18715	12232	7891	5596	2892	1939	762	719	41
OTHER HARD HARDWOODS	1947501	1469146	315101	86103	34120	18256	10795	6510	2913	2123	931	1377	126
TROPICALS AND MISC. SPP.	1589528	1187357	291264	77602	22875	6922	2217	862	270	90	55	13	1
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	4306951	3170928	732948	216371	87747	43181	24245	14935	7219	4836	1991	2362	188
ALL SPECIES	16549470	10569762	3020214	1293923	712747	414572	238960	139713	75758	40299	19694	21325	2503

Table 18. Merchantable cubic volume of all live trees on commercial forest land, North Carolina, by species and diameter class, 1974

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND CUBIC FEET							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	5033502	0	0	474355	695737	789282	857121	767196	619577	392420	285771	200532	11911
LONGLEAF PINE	484970	0	0	41456	82909	97607	103772	68262	35289	17225	4459	3991	0
POND PINE	1029904	0	0	155794	209228	252099	165454	120733	70204	31750	17977	6665	0
SHORTLEAF PINE	1599356	0	0	233155	390187	424529	260119	156421	63467	30066	12370	7042	0
SLASH PINE	19621	0	0	12138	6614	871	0	0	246	0	0	0	0
VIRGINIA PINE	1128718	0	0	270613	334422	281011	145830	64314	22087	7511	2945	385	0
OTHER YELLOW PINES	216327	0	0	25775	43062	49633	32396	24535	14928	7134	5647	2217	0
TOTAL YELLOW PINES	9482698	0	0	1213296	1762359	1894782	1590692	1223461	830600	486106	348769	220832	11811
OTHER SOFTWOODS:													
EASTERN WHITE PINE	425907	0	0	24248	52589	52376	50176	53876	50725	43922	24307	55349	18337
CYPRESS	334022	0	0	14735	26826	45722	47533	44952	35923	32237	25500	47835	12969
OTHER SOFTWOODS	330649	0	0	50634	46993	56217	31961	37389	21856	12567	23670	28855	20537
TOTAL OTHER SOFTWOODS	1090776	0	0	89577	126408	154315	129672	136217	108504	88726	73477	132039	51843
SOFT HARDWOODS:													
SWEETGUM	1673046	0	0	198508	271126	275491	260511	207431	162179	116336	64006	86216	11242
YELLOW POPLAR	2064016	0	0	162376	234755	297680	362019	334313	239635	168468	104615	149376	10863
TUPELO AND BLACKGUM	1956095	0	0	170622	252892	279093	265912	278914	216995	169286	102769	152559	46433
BAY AND MAGNOLIA	101654	0	0	18606	19184	15618	13374	16264	8907	7548	2748	2693	710
SOFT MAPLES	1639167	0	0	278223	282421	279765	237550	184444	125668	90720	60505	88931	10740
OTHER SPECIES	643977	0	0	61542	110336	102240	99782	77419	62664	37165	23805	41177	7847
TOTAL SOFT HARDWOODS	8077957	0	0	909681	1170714	1250687	1259144	1098765	836446	585523	358468	520652	87655
OAKS:													
BLACK	453312	0	0	42435	49962	67139	68599	55840	53396	34318	24060	45565	11998
CHESTNUT	970375	0	0	69955	102017	137437	127816	141150	112088	71743	60006	121726	26437
LAUREL	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHERN RED	663556	0	0	40758	54650	71542	74185	72633	77360	65645	64239	120817	41729
SCARLET	760480	0	0	68400	96898	125740	120530	113220	81677	69906	36503	45048	2358
SOUTHERN RED	405259	0	0	40616	60836	59404	71484	57117	43626	30164	14767	21742	5499
WATER	524122	0	0	77143	74778	73121	67215	56044	42104	37978	23649	50691	21399
WHITE	1553014	0	0	143195	171667	234646	243692	207038	161433	126249	83877	134534	26663
OTHER OAKS	662845	0	0	68296	82215	96291	88714	75158	63480	45797	29333	79995	33564
SCRUB OAKS	60621	0	0	21382	18634	11836	6414	1394	956	285	0	0	0
TOTAL OAKS	6073786	0	0	572184	711659	877156	868049	779594	656326	482005	336434	620118	169667
OTHER HARDWOODS:													
ASH	405229	0	0	55461	70253	62028	59140	51383	41581	31870	12797	17612	2904
HICKORY	912063	0	0	78141	108976	128190	139127	146407	107209	90212	45661	61112	7028
OTHER HARD HARDWOODS	1252370	0	0	198810	162463	184663	175641	154373	93864	69990	46788	105787	17991
TROPICALS AND MISC. SPP.	352667	0	0	158140	95077	50307	24180	13267	6103	2670	2113	634	176
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2922329	0	0	490552	456769	425188	398088	365430	248757	214742	109359	185345	28099
ALL SPECIES	27647748	0	0	3275480	4227909	4602128	4246245	3603487	2660629	1857102	1126507	1678986	349075

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND CUBIC FEET							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	6460242	120540	414163	674695	848616	920273	981109	892647	698693	441070	230790	224427	13219
LONGLEAF PINE	570906	7758	30513	57466	99641	112764	117813	76789	39522	19241	4981	4418	0
POND PINE	1242374	28228	102273	144096	195811	297265	191305	138701	60388	36226	20497	7584	0
SHORTLEAF PINE	2074339	30025	132704	318341	470788	494031	320857	180056	71777	33917	13922	7921	0
SLASH PINE	53186	6179	20367	17358	8278	726	0	0	278	0	0	0	0
VIRGINIA PINE	1761342	97513	295981	357327	401896	328874	168591	73943	25302	8579	2901	435	0
OTHER YELLOW PINES	280738	4864	20655	33495	51233	57717	44306	28180	22826	8168	6573	2521	0
TOTAL YELLOW PINES	12443127	295107	1016856	1602778	2076263	2211650	1823981	1390316	938786	547201	279664	247306	13219
OTHER SOFTWOODS:													
EASTERN WHITE PINE	524474	7706	16251	31488	63641	61760	58582	62523	58747	50746	28048	63833	21149
CYPRESS	431653	2677	7273	22154	35292	57854	59255	55365	44155	39369	31184	58769	18306
OTHER SOFTWOODS	492254	34322	54609	72026	58948	68060	37866	43481	25288	14478	27124	32791	23261
TOTAL OTHER SOFTWOODS	1448381	44705	78133	125668	157881	187674	155703	161369	128190	104593	86356	155393	62716
SOFT HARDWOODS:													
SWEETGUM	2458941	182678	246737	293817	338552	326943	303268	239002	209137	133009	73228	99430	13140
YELLOW POPLAR	2606944	68017	148551	216138	279793	344032	412792	378502	270544	189991	117726	167947	12911
TUPELO AND BLACKGUM	2810426	153355	188643	253800	327691	347766	355978	342578	265942	205830	125210	186227	57206
BAY AND MAGNOLIA	237459	58379	48380	26831	25525	19610	17482	19639	10419	4145	3143	3045	861
SOFT MAPLES	2988174	383034	516473	409086	364170	346133	293714	224315	151925	108744	72097	105618	12865
OTHER SPECIES	932456	63377	78744	116441	137885	122415	120629	91370	73386	43314	27862	47926	9107
TOTAL SOFT HARDWOODS	12034400	908840	1227528	1316113	1473816	1506899	1503863	1295406	981353	685033	419266	610193	106090
OAKS:													
BLACK	629355	12936	35028	64868	86054	85352	86096	69220	65943	42638	29774	56597	14849
CHESTNUT	1314103	18032	68451	100068	132298	172404	159462	174645	138364	89460	74291	152900	33708
LAUREL	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHERN RED	908297	15293	29090	56520	70449	89906	92633	90855	96274	61682	79576	151243	54776
SCARLET	1017260	14483	37918	96890	124977	157941	150133	140901	101260	86502	45465	57766	3024
SOUTHERN RED	610909	28345	53383	66915	82580	76316	89316	70694	53804	36900	18176	27443	7037
WATER	854951	67079	89419	122953	102301	95936	87976	71611	53052	47237	29233	62231	25923
WHITE	2158930	55693	116127	212255	225483	298044	305494	257260	224929	156991	103831	168872	33951
OTHER OAKS	954533	34353	52371	108810	110583	123744	112368	94446	80068	57298	36872	100440	43180
SCRUB OAKS	171701	36493	43471	33568	25298	15353	12584	2704	1844	386	0	0	0
TOTAL OAKS	8620039	282707	525258	862847	940023	1114996	1096082	972336	815538	599094	417218	777492	216448
OTHER HARDWOODS:													
ASH	610342	52996	58287	83677	88098	73599	69723	60024	47902	36720	14940	20812	3564
HICKORY	1306078	53276	89642	123667	144419	161373	170615	179049	131097	111092	56226	76115	9507
OTHER HARD HARDWOODS	2271780	330204	390463	234985	223831	225848	223176	193981	117521	112216	61471	132873	25211
TROPICALS AND MISC. SPP.	1092548	245503	360195	226134	128525	66948	32180	17655	8021	3512	2783	863	229
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	5280748	681979	898587	668463	584873	527768	495694	450709	304541	263540	135420	230663	38511
ALL SPECIES	39826695	2213338	3746362	4575869	5232856	5548987	5075323	4270136	3168408	2199461	1337924	2021047	436984

Table 20.—Merchantable green weight of all live trees on commercial forest land, North Carolina, by species and diameter class, 1974

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-24	26+
	HUNDRED THOUSAND POUNDS												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	3704587	0	0	357394	516170	584364	629457	575654	451914	285739	149674	145690	6571
LONGLEAF PINE	352153	0	0	29911	63927	74932	61076	53023	28006	13725	3560	3198	0
POND PINE	702295	0	0	97631	131053	178171	118022	86451	50405	22620	12940	4800	0
SHORTLEAF PINE	1124174	0	0	151314	270872	306242	201413	113699	48500	21535	8858	5841	0
SLASH PINE	14652	0	0	8791	5212	458	0	0	191	0	0	0	0
VIRGINIA PINE	806426	0	0	225631	250816	208948	108247	47696	16367	5564	1884	279	0
OTHER YELLOW PINES	144571	0	0	16505	30064	32337	25411	16437	13946	4891	3862	1498	0
TOTAL YELLOW PINES	6907633	0	0	887177	1267744	1385452	1163626	893754	609929	354274	180800	160506	6571
OTHER SOFTWOODS:													
EASTERN WHITE PINE	282649	0	0	16630	35120	34903	33992	36459	34046	29211	15967	35107	11214
CYPRESS	243159	0	0	7365	15299	30605	33616	33259	27473	25193	20336	39005	11006
OTHER SOFTWOODS	255087	0	0	41539	34976	41869	24701	29666	17333	9992	18463	21857	14689
TOTAL OTHER SOFTWOODS	780895	0	0	65534	85395	107377	92311	99386	78852	64396	54766	95969	36909
SOFT HARDWOODS:													
SWEETGUM	1240656	0	0	149682	196623	201331	191467	153457	136016	87700	48681	66688	9013
YELLOW POPLAR	1466742	0	0	110514	160725	206427	256942	239853	173666	122681	76928	110733	8073
TUPELO AND BLACKGUM	1301149	0	0	99682	152000	175636	184919	188611	151276	120942	75118	115404	37561
BAY AND MAGNOLIA	63641	0	0	10162	11161	9391	6181	10929	6430	2608	2099	2087	593
SOFT MAPLES	1233310	0	0	206259	213976	213718	173506	138328	95622	69382	46402	68031	8086
OTHER SPECIES	429544	0	0	51778	70361	67208	63786	51702	43134	26357	17333	31571	6314
TOTAL SOFT HARDWOODS	5735044	0	0	628077	804646	873711	878801	782880	606144	429370	266561	394514	69640
OAKS:													
BLACK	405999	0	0	40360	45897	60992	62116	49441	46783	29909	20869	39321	10311
CHESTNUT	768989	0	0	53578	77966	106913	98433	111272	69696	58132	49048	101332	22617
LAUREL	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHERN RED	564376	0	0	31537	44400	59709	60848	59931	64063	54555	53489	100967	34877
SCARLET	666954	0	0	59924	85339	111442	107771	99232	71016	60257	31364	38592	2015
SOUTHERN RED	331474	0	0	27037	43676	45412	61742	49394	38242	26627	13350	20348	5444
WATER	430260	0	0	61354	60735	59634	54812	46599	35305	31946	19888	42486	17499
WHITE	1265215	0	0	109410	135268	190368	204137	173912	153197	107248	71755	116343	23577
OTHER OAKS	563494	0	0	49761	65404	80740	74669	64470	55394	40581	26527	73513	32435
SCRUB OAKS	66334	0	0	25110	20063	12387	6360	1340	686	188	0	0	0
TOTAL OAKS	5083095	0	0	458671	578750	727597	730888	655591	554586	409643	286290	532904	148775
OTHER HARDWOODS:													
ASH	260049	0	0	40756	46247	40428	37101	31369	24861	18625	7321	9908	1433
HICKORY	746456	0	0	57915	84943	104536	113922	120461	89345	76055	39062	53618	6599
OTHER HARD HARDWOODS	1062163	0	0	148483	148080	159040	154280	134921	82469	79533	43206	95841	16310
TROPICALS AND MISC. SPP.	258653	0	0	123911	66629	33060	17997	9378	4116	1751	1336	382	91
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2327321	0	0	371065	347899	337064	323300	296129	200793	175964	90925	159749	24433
ALL SPECIES	20834188	0	0	2409924	3084634	3431201	3188926	2727740	2046304	1434147	879342	1343642	288328

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
		- - - - - - - - - - - - - - - - - - HUNDRED THOUSAND POUNDS - - - - - - - - - - - - - - - - - -											
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	4715568	86330	265209	508694	629450	661375	720473	652739	509634	321166	167852	163053	9593
LONGLEAF PINE	438887	5671	21639	41338	76823	86574	92060	60558	31373	15335	3975	3541	0
POND PINE	989346	20277	66459	161750	191099	210013	136471	99307	57708	26038	14761	5463	0
SHORTLEAF PINE	1459953	23918	95880	206040	326380	356401	230700	129237	51465	24295	9967	5670	0
SLASH PINE	38594	4513	14460	12543	6326	536	0	0	214	0	0	0	0
VIRGINIA PINE	1333347	71262	209822	298745	301473	244515	125134	54827	18749	6356	2149	315	0
OTHER YELLOW PINES	188679	3546	14797	21439	35770	37592	29321	18879	15516	5601	4515	1703	0
TOTAL YELLOW PINES	9164374	215517	688266	1250549	1567321	1617008	1334159	1015547	684659	398791	203219	179745	9593
OTHER SOFTWOODS:													
EASTERN WHITE PINE	348540	5640	10638	21599	42509	41146	39681	42310	39428	33740	18427	40489	12933
CYPRESS	313282	2045	5384	11056	20136	38693	41885	40973	33783	30763	24873	47923	15768
OTHER SOFTWOODS	378576	26273	40598	59199	43891	50636	29254	34494	20065	11518	21166	24642	16640
TOTAL OTHER SOFTWOODS	1040398	33958	56620	91854	106536	130475	110820	117777	93276	76021	64466	113254	45341
SOFT HARDWOODS:													
SWEETGUM	1860069	150655	203608	222160	245459	238922	222878	176815	156126	100279	55695	76931	10541
YELLOW POPLAR	1848185	49027	102020	147089	191521	238415	292989	271562	195898	138591	86571	124734	9768
TUPELO AND BLACKGUM	1909932	123138	150685	148187	196916	218295	230036	231602	185362	147033	91505	140886	46287
BAY AND MAGNOLIA	157124	42535	33404	14652	14836	11795	10664	13186	7522	3046	2402	2363	719
SOFT MAPLES	2226174	286671	369078	303178	275801	264397	214520	168202	115420	83159	55275	80794	9679
OTHER SPECIES	632504	48275	58242	74050	87915	80474	76993	61018	50485	30722	20281	36719	7330
TOTAL SOFT HARDWOODS	8633988	700301	917037	909316	1012448	1052298	1048080	922385	710813	502830	311729	462427	84324
OAKS:													
BLACK	565829	12588	31572	61811	60695	77536	77962	61295	57782	37156	25826	48842	12764
CHESTNUT	1048405	16386	59710	76660	101087	134123	122835	137689	110723	72470	60710	127211	28801
LAUREL	0	0	0	0	0	0	0	0	0	0	0	0	0
NORTHERN RED	754007	14770	26362	43708	57240	75033	75981	74977	79735	67878	66256	126356	45711
SCARLET	894537	13940	34419	84892	110070	139965	134245	123483	87829	74568	39061	49482	2583
SOUTHERN RED	505065	27402	48325	44406	59252	58333	77148	61143	47163	32817	16433	25678	6965
WATER	717940	65078	80436	97702	83087	78255	71656	59540	44498	39734	24563	52153	21218
WHITE	1786113	46344	96141	162073	177643	241801	255920	216087	189933	133353	88828	146013	29977
OTHER OAKS	811909	31895	45329	79297	87955	103769	94576	81009	69857	50772	33340	92300	41810
SCRUB OAKS	183718	40577	43150	39537	27250	16068	12472	2600	1710	354	0	0	0
TOTAL OAKS	7267523	270980	465444	690086	764279	924883	922795	817823	689230	509102	355037	668035	189829
OTHER HARDWOODS:													
ASH	413178	43259	47512	61608	60514	47972	43725	36634	28637	21458	8537	11563	1759
HICKORY	1076973	49285	78327	91581	112518	131563	139704	147315	109244	93646	48093	66781	8916
OTHER HARD HARDWOODS	1924955	279422	328803	175173	181851	194574	195638	169471	103298	99224	54432	120359	22710
TROPICALS AND MISC. SPP.	651822	205440	288378	177367	90088	43999	23951	12484	5415	2302	1761	519	118
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	4266928	577406	743020	505729	444971	418108	403018	365904	246594	216630	112823	199222	33503
ALL SPECIES	30373211	1798162	2870387	3447534	3895555	4142772	3818872	3239436	2424572	1703374	1047274	1622683	362590

Table 22 Number of all live trees on commercial forest land, South Carolina, by species and diameter class, 1978

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND TREES							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	1419136	578973	327824	203105	128566	77220	46989	27340	15247	7644	3378	2750	100
LONGLEAF PINE	128954	42135	26689	18235	14586	11409	8041	4823	2111	692	162	66	5
POND PINE	103058	25109	28221	19008	12565	7689	4985	2681	1375	589	279	157	0
SHORTLEAF PINE	535107	252283	133343	70031	43244	21510	9440	3340	1371	462	69	52	2
SLASH PINE	193131	40307	59327	49219	27443	10512	4118	1177	681	251	55	41	0
VIRGINIA PINE	120536	53632	28815	17198	10947	6061	2442	1046	234	131	15	13	0
OTHER YELLOW PINES	5817	1418	1006	1003	746	572	491	220	157	91	70	46	0
TOTAL YELLOW PINES	2505739	993857	605225	377796	238097	135173	76506	40829	21136	9860	4028	3125	107
OTHER SOFTWOODS:													
EASTERN WHITE PINE	6344	3923	1708	0	198	87	96	83	75	51	24	91	8
CYPRESS	68456	28150	11321	8054	5660	4972	3092	2697	1871	994	706	795	144
OTHER SOFTWOODS	236617	175337	44497	10845	3712	1525	446	89	55	41	27	43	0
TOTAL OTHER SOFTWOODS	311417	207410	57526	18899	9570	6584	3634	2869	2001	1086	757	929	152
SOFT HARDWOODS:													
SWEETGUM	1226273	816166	225189	87690	42414	23061	14324	7685	4453	2534	1207	1240	110
YELLOW POPLAR	122951	69179	15265	12237	7484	6030	4371	3199	2081	1389	856	805	55
TUPELO AND BLACKGUM	730767	474223	108563	48713	32288	21966	17540	11802	6844	3891	2022	2529	386
BAY AND MAGNOLIA	200467	180174	14826	3475	1150	360	217	120	61	12	18	25	9
SOFT MAPLES	815196	618957	115132	38882	18002	10234	5785	3514	2186	1384	700	635	85
OTHER SPECIES	348682	243595	54857	23736	11433	6011	4249	1952	1071	687	420	542	129
TOTAL SOFT HARDWOODS	3444336	2402294	533832	214733	112771	67662	46486	28472	16716	9597	5223	5776	774
OAKS:													
BLACK	44140	18967	14384	4138	2601	1680	981	504	270	172	128	103	12
CHESTNUT	16136	7721	1880	2370	1361	1131	753	411	224	160	24	95	6
LAUREL	161222	95773	30621	12156	7395	4483	3159	2365	1744	1099	703	1341	303
NORTHERN RED	32526	15939	7126	3413	1738	1030	1260	679	386	237	63	55	0
SCARLET	36854	11961	9679	5899	3812	2303	1541	791	439	236	87	100	6
SOUTHERN RED	149809	78074	35117	17201	9083	4160	2913	1437	977	356	183	262	44
WATER	465182	313852	80684	34145	17158	9259	4434	2293	1384	806	458	430	79
WHITE	179329	87465	41239	20964	12066	7707	4188	2596	1598	710	391	351	54
OTHER OAKS	309917	184024	57821	27997	15210	8756	5966	3867	2346	1431	876	1327	296
SCRUB OAKS	438209	349661	64808	16603	5253	1393	339	116	15	5	0	14	0
TOTAL OAKS	1833326	1163437	343559	144886	75877	42499	25534	15059	9385	5214	2993	4083	800
OTHER HARDWOODS:													
ASH	287671	209919	44612	14143	7145	5181	2756	1931	823	583	272	267	39
HICKORY	259151	177457	38249	19731	10419	5117	3218	2216	1171	661	365	469	78
OTHER HARD HARDWOODS	662094	527763	95991	24513	6952	2916	1672	807	537	275	190	264	14
TROPICALS AND MISC. SPP.	462473	366802	83829	21364	6483	2818	686	263	125	62	19	19	3
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	1691389	1281941	262681	79751	30999	16032	8532	5217	2656	1581	846	1019	134
ALL SPECIES	9786207	6046939	1802823	836065	467314	267950	160692	92446	51694	27338	13847	14932	1967

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND CUBIC FEET							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	5442108	0	0	508673	801060	904416	901960	779949	610661	405343	234279	276384	19383
LONGLEAF PINE	699227	0	0	53195	95633	138532	154386	132722	76651	32785	8992	5708	623
POND PINE	479421	0	0	45739	77076	88522	89016	74231	48363	27342	16666	12466	0
SHORTLEAF PINE	1041055	0	0	175521	267248	245781	174401	93955	51963	23024	4199	4585	378
SLASH PINE	583840	0	0	128845	174013	120751	78044	34382	27535	12494	3738	4038	0
VIRGINIA PINE	272243	0	0	50849	72019	67909	41695	25278	7445	5156	884	1008	0
OTHER YELLOW PINES	47437	0	0	2591	5273	6776	9411	5205	5333	4211	4471	4166	0
TOTAL YELLOW PINES	8565331	0	0	965413	1492322	1572687	1448913	1145722	827951	510355	273229	308355	20384
OTHER SOFTWOODS:													
EASTERN WHITE PINE	23448	0	0	0	1082	1098	1686	2173	2693	2344	1551	9828	993
CYPRESS	511987	0	0	25734	38179	63788	59294	74048	67932	46759	42132	70251	23870
OTHER SOFTWOODS	72552	0	0	23837	17633	14021	6301	2109	1728	1439	1508	3976	0
TOTAL OTHER SOFTWOODS	607987	0	0	49571	56894	78907	67281	78330	72353	50542	45191	84055	24863
SOFT HARDWOODS:													
SWEETGUM	1814882	0	0	205167	261363	282071	286572	227033	184097	136212	85066	125686	21615
YELLOW POPLAR	622006	0	0	35982	50434	73907	85008	89277	80413	70711	55046	70282	10946
TUPELO AND BLACKGUM	1899624	0	0	137713	198791	249376	309906	292674	228431	162481	104526	173303	42423
BAY AND MAGNOLIA	32739	0	0	9421	6406	3616	3496	2381	2540	474	717	1600	2088
SOFT MAPLES	736562	0	0	118585	111891	112177	96737	85423	70462	45040	37163	48381	10703
OTHER SPECIES	514969	0	0	61336	68716	66639	77404	53285	42089	35427	27951	54267	27855
TOTAL SOFT HARDWOODS	5620782	0	0	568204	697601	787786	859123	750073	608032	450345	310469	473519	115630
OAKS:													
BLACK	103600	0	0	11301	15773	15063	15307	12308	8514	7298	7107	8657	1672
CHESTNUT	70044	0	0	5873	8181	11932	12034	9387	7316	6674	824	6546	1277
LAUREL	597650	0	0	37633	48374	54921	58913	64219	62948	52386	47146	118055	53055
NORTHERN RED	118953	0	0	11139	11780	20022	22008	19251	13551	12027	3918	5257	0
SCARLET	162514	0	0	17827	25327	27011	28988	20586	16373	11784	5318	8090	1210
SOUTHERN RED	301474	0	0	42724	50765	42889	49105	33175	30979	14202	10422	19812	7401
WATER	592248	0	0	102788	102798	98764	75369	55106	46418	34920	27591	35204	13290
WHITE	532603	0	0	59221	77055	88876	78235	70026	58236	36218	23898	31650	8968
OTHER OAKS	820811	0	0	74965	87440	91030	100512	97121	82147	64655	50200	117471	55270
SCRUB OAKS	77889	0	0	37101	22345	11043	4359	2144	243	190	0	464	0
TOTAL OAKS	3377786	0	0	400572	449638	462151	444830	383323	326725	240354	176424	351406	142163
OTHER HARDWOODS:													
ASH	367931	0	0	41778	45430	62955	54661	52949	31237	29217	17130	26320	6254
HICKORY	445253	0	0	49736	59118	53791	57935	58383	45735	33878	23773	45750	17154
OTHER HARD HARDWOODS	241876	0	0	53671	36787	31341	31488	21096	18151	12688	11360	23608	1486
TROPICALS AND MISC. SPP.	124224	0	0	50533	28773	22917	8945	5039	3433	1793	1436	1066	289
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	1179284	0	0	195718	170108	171004	153029	137467	98556	77776	53699	96744	25183
ALL SPECIES	19351170	0	0	2179478	2866763	3072535	2973176	2494915	1933617	1329372	859012	1314079	326223

Table 24 Total cubic volume of all live trees on commercial forest land, South Carolina, by species and diameter class, 1978

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
	THOUSAND CUBIC FEET												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	6825436	91345	326991	721476	976346	1055086	1032300	884296	668551	455563	262678	309184	21618
LONGLEAF PINE	858321	11657	34322	73203	115197	100064	175200	149272	85783	36567	10004	6341	711
POND PINE	600019	5298	29230	61362	92846	103536	102840	85202	59313	31216	16988	14186	0
SHORTLEAF PINE	1409333	38555	119007	241655	322647	285867	199753	106769	58766	26001	4734	5153	424
SLASH PINE	814065	13240	68358	161136	210453	139955	68757	38722	30846	13946	4162	4490	0
VIRGINIA PINE	384639	13569	43969	67585	66449	79316	48134	29033	8816	5689	1008	1149	0
OTHER YELLOW PINES	57106	568	1516	3614	6335	7895	10788	5917	6024	4754	5014	4681	0
TOTAL YELLOW PINES	10948921	174272	643393	1350033	1810273	1831719	1657772	1299213	933803	577936	306588	345166	22753
OTHER SOFTWOODS:													
EASTERN WHITE PINE	29503	735	1557	0	1305	1290	1969	2522	3117	2706	1790	11667	1143
CYPRESS	664231	5959	13366	39570	51083	61401	74051	91494	83324	56990	51332	65538	30127
OTHER SOFTWOODS	168346	29357	42672	35966	22754	17204	7556	2471	2037	1718	1804	4616	0
TOTAL OTHER SOFTWOODS	862082	36051	57795	75536	75142	99895	83576	96487	88477	61416	54926	101515	31266
SOFT HARDWOODS:													
SWEETGUM	2544034	134786	223225	304406	325436	333977	332423	260854	210631	155012	96503	142709	24670
YELLOW POPLAR	750858	15904	19343	48385	60044	85285	96796	101093	90691	79546	61873	79528	12370
TUPELO AND BLACKGUM	2644713	105654	126095	204926	258512	313559	364786	361800	262239	201388	129852	219216	56686
BAY AND MAGNOLIA	90565	30882	16793	14410	8113	4390	4181	2657	2996	557	900	1905	2581
SOFT MAPLES	1238608	142602	176107	169164	140623	136924	116624	102451	84313	54025	44504	58190	13081
OTHER SPECIES	741110	46185	68905	88663	65605	79874	91351	62409	49107	41226	32470	62862	32451
TOTAL SOFT HARDWOODS	8009888	476013	630468	829956	878333	954009	1026161	891464	719377	531756	366102	564410	141839
OAKS:													
BLACK	155557	4266	18050	16960	20767	19922	19107	15269	10579	9028	6766	10657	2186
CHESTNUT	91428	1568	1623	8335	10452	14867	14672	11550	9001	8249	1039	8179	1693
LAUREL	827612	19973	34146	58460	65220	71205	75296	81244	79601	65840	59379	149417	67831
NORTHERN RED	161707	3330	8662	15195	15064	25136	27469	23654	16757	14876	4884	6476	0
SCARLET	220511	2881	12163	25076	32579	33787	35947	25409	20134	14456	6580	9986	1513
SOUTHERN RED	451275	15208	37829	70840	68791	54797	61262	40978	37983	17459	12704	24191	9173
WATER	945302	63035	91514	162831	138568	127361	95480	69305	58231	43673	34434	44159	16711
WHITE	749519	20560	46462	87742	100739	112508	97696	86892	71929	44651	29637	39337	11764
OTHER OAKS	1156933	36854	61437	117693	117172	116803	126481	121134	102033	80213	62143	145312	69658
SCRUB OAKS	232689	56205	23840	58225	30518	14376	5574	2729	326	238	0	656	0
TOTAL OAKS	4992533	223940	375726	621357	599870	590764	559186	478364	406574	298685	219566	438372	180129
OTHER HARDWOODS:													
ASH	523326	38882	44821	59343	55846	74221	63308	60980	35639	33356	19527	29969	7234
HICKORY	648267	35961	44094	78264	78220	67655	71294	71231	55446	41031	28737	55544	20790
OTHER HARD HARDWOODS	537330	113904	106325	81343	48168	39320	39009	26055	22368	15666	14002	29075	2095
TROPICALS AND MISC. SPP.	338976	72560	90170	78093	39146	30283	11678	6580	4505	2405	1817	1373	364
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2047899	261307	285410	297043	221382	211479	185289	164846	118158	92458	64083	115961	30483
ALL SPECIES	26861323	1171583	1992792	3173925	3585000	3687866	3511984	2930374	2266389	1558251	1012651	1565424	406470

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						HUNDRED THOUSAND POUNDS							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	4007192	0	0	383676	594402	670303	662603	570393	445399	295156	170410	200787	14061
LONGLEAF PINE	545113	0	0	39063	73858	106819	121061	104975	60919	26152	7185	4580	501
POND PINE	343409	0	0	33570	55017	62759	63544	53171	34720	19657	11992	8979	0
SHORTLEAF PINE	727865	0	0	112640	184517	177491	125469	67436	37257	16499	3006	3280	270
SLASH PINE	447554	0	0	96958	135525	91657	59862	26526	21306	9678	2900	3142	0
VIRGINIA PINE	208550	0	0	43245	54342	50520	30958	18745	5519	3820	654	747	0
OTHER YELLOW PINES	33754	0	0	1825	3806	4713	6599	3719	3820	3012	3238	3022	0
TOTAL YELLOW PINES	6313437	0	0	710979	1101467	1164262	1070096	844965	608940	373974	199385	224537	14832
OTHER SOFTWOODS:													
EASTERN WHITE PINE	15238	0	0	0	732	733	1143	1469	1802	1556	1011	6172	620
CYPRESS	374697	0	0	12799	21590	41959	42131	55180	52088	36611	33654	57732	20953
OTHER SOFTWOODS	55608	0	0	19091	13452	10230	4701	1651	1298	1105	1121	2959	0
TOTAL OTHER SOFTWOODS	445543	0	0	31890	35774	52922	47975	58300	55188	39272	35786	66863	21573
SOFT HARDWOODS:													
SWEETGUM	1350504	0	0	154627	190260	206301	210786	168091	137645	102831	64874	97617	17472
YELLOW POPLAR	445644	0	0	24516	34586	51235	60272	64052	58233	51644	40483	52272	8351
TUPELO AND BLACKGUM	1296646	0	0	75889	119445	158094	200004	199877	163360	120632	79700	141556	38089
BAY AND MAGNOLIA	20742	0	0	5140	3850	2288	2132	1548	1807	354	552	1267	1804
SOFT MAPLES	555001	0	0	87506	85087	85832	70668	64107	53544	34465	28521	37115	8156
OTHER SPECIES	353135	0	0	39307	44057	43731	49078	36121	29468	25683	20938	42154	22598
TOTAL SOFT HARDWOODS	4021672	0	0	386985	477285	547481	592940	533796	444057	335609	235068	371981	96470
OAKS:													
BLACK	93208	0	0	10773	14518	14242	13909	10904	7465	6352	6153	7456	1436
CHESTNUT	55251	0	0	4528	6275	9259	9215	7368	5865	5433	668	5499	1141
LAUREL	485802	0	0	29030	39273	45301	47725	52552	51670	43002	38630	96139	42480
NORTHERN RED	97639	0	0	8474	9591	16764	18018	15895	11219	10007	3269	4402	0
SCARLET	142621	0	0	15615	22343	23947	25802	18041	14187	10150	4567	6932	1037
SOUTHERN RED	244674	0	0	28782	36692	32939	42409	28707	27095	12601	9466	18463	7520
WATER	484870	0	0	81527	83574	80464	61655	45752	38860	29316	23190	29511	11021
WHITE	438958	0	0	45232	60985	72215	65553	58838	49179	30831	20462	27627	8036
OTHER OAKS	706984	0	0	55258	69468	75642	85089	84086	72416	57888	45498	108706	52931
SCRUB OAKS	85325	0	0	42651	24183	11388	4266	2031	228	171	0	407	0
TOTAL OAKS	2835332	0	0	321870	366902	382161	373641	324176	278184	205751	151903	305142	125602
OTHER HARDWOODS:													
ASH	232629	0	0	30557	31189	40827	34407	32475	18673	17059	9806	14398	3238
HICKORY	365743	0	0	36546	46023	43878	47347	48046	38169	28665	20411	40519	16139
OTHER HARD HARDWOODS	199001	0	0	40107	29086	25689	25831	17861	15710	11446	10045	21767	1459
TROPICALS AND MISC. SPP.	86178	0	0	38560	20421	15046	5276	2809	1806	930	660	516	134
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	883551	0	0	145770	126719	125440	112861	101191	74358	58100	40942	77200	20970
ALL SPECIES	14499535	0	0	1597494	2108147	2272266	2197513	1862428	1460727	1012706	663084	1045723	279447

Table 26 Total green weight of all live trees on commercial forest land, South Carolina, by species and diameter class, 1978

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						HUNDRED THOUSAND POUNDS							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	4998283	65732	211024	544636	724492	762006	758357	646686	502237	331721	191060	224626	15668
LONGLEAF PINE	665415	8537	24457	53611	68953	123412	137366	118069	68181	29171	7996	9086	572
POND PINE	427852	3754	18836	45091	66272	73404	73415	61040	39706	22447	13663	10220	0
SHORTLEAF PINE	989502	30933	86372	154611	222714	206421	143671	76633	42136	18627	3391	7688	303
SLASH PINE	618034	9665	62821	136085	163893	106256	68056	29865	23665	10805	3230	3491	0
VIRGINIA PINE	292705	9954	31251	57715	65244	59000	35734	21531	6315	4364	747	850	0
OTHER YELLOW PINES	40626	428	1076	2547	4574	5492	7557	4226	4316	3396	3633	3379	0
TOTAL YELLOW PINES	8032419	129003	435841	994298	1336142	1355991	1224160	958052	686760	420533	223740	251336	16563
OTHER SOFTWOODS:													
EASTERN WHITE PINE	19227	528	1014	0	683	861	1336	1705	2085	1798	1166	7139	712
CYPRESS	463521	4546	9897	19670	28897	53451	52594	68182	63906	44630	41015	70316	26417
OTHER SOFTWOODS	128273	22446	31870	28859	17363	12553	5633	1934	1527	1318	1342	3428	0
TOTAL OTHER SOFTWOODS	631021	27520	42781	48529	47143	66865	59563	71821	67518	47746	43523	80883	27129
SOFT HARDWOODS:													
SWEETGUM	1922407	111107	184200	229857	236931	244259	244506	193114	157034	117017	73601	110639	19942
YELLOW POPLAR	537092	11466	13317	32963	41180	59131	68619	72529	65681	58102	45512	59151	9441
TUPELO AND BLACKGUM	1829323	84802	100742	112508	155263	198804	248256	247208	202056	149754	99229	179596	51103
BAY AND MAGNOLIA	60962	22498	11607	7619	4876	2778	2546	1857	2130	417	693	1508	2229
SOFT MAPLES	925228	106698	125924	124690	106941	104767	85167	76879	64067	41343	34151	44639	9962
OTHER SPECIES	514319	35235	50979	56900	54887	52402	57916	42294	34372	29883	24323	48816	26318
TOTAL SOFT HARDWOODS	5789331	371806	486769	564737	600080	662141	707012	633681	525340	396516	277509	444545	118995
OAKS:													
BLACK	140482	4144	16245	16191	19118	18119	17361	13521	9279	7856	7591	9179	1878
CHESTNUT	72452	1428	1432	6428	8016	11540	11387	9064	7214	6714	842	6672	1515
LAUREL	678574	19423	30913	44996	52924	58731	61003	66491	65339	54053	48664	121702	54335
NORTHERN RED	133837	3244	7803	11539	12268	21052	22484	19693	13875	12379	4076	5424	0
SCARLET	194048	2784	10938	21965	28731	29958	32005	22268	17448	12450	5651	8555	1295
SOUTHERN RED	369026	14916	34297	47595	49690	42075	52904	35455	33214	15491	11538	22532	9319
WATER	790403	61406	82762	128948	112656	103754	78103	57545	48745	36662	28931	37026	13865
WHITE	617645	17789	38484	66968	79711	91417	81858	73007	60744	38011	25381	34113	10162
OTHER OAKS	994844	33575	53091	86738	93104	97073	107064	104873	89947	71832	56329	134481	66737
SCRUB OAKS	249798	61982	63762	67037	33043	14633	5456	2584	305	215	0	581	0
TOTAL OAKS	4241109	220691	339727	498405	489261	488552	469625	404501	346110	255663	189003	380465	159106
OTHER HARDWOODS:													
ASH	347750	31753	36532	43486	38350	48154	39858	37398	21421	19478	11180	16393	3747
HICKORY	536686	33228	38733	57406	60854	55171	58261	58605	46272	34720	24663	49197	19556
OTHER HARD HARDWOODS	445743	96560	89497	60794	38110	32222	31992	22055	19354	13913	12377	26801	2068
TROPICALS AND MISC. SPP.	256494	60794	72457	59689	27808	19876	6888	3668	2372	1247	861	665	169
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	1586673	222335	237219	221375	165122	155423	136999	121726	89419	69358	49101	93056	25540
ALL SPECIES	20280553	971355	1542337	2327344	2637748	2728972	2597359	2189981	1715147	1189816	782876	1250285	347333

Table 27.- Number of all live trees on commercial forest land, Virginia, by species and diameter class, 1977

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND TREES							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	737357	300651	202401	109090	53996	29820	19641	11312	6070	2724	1027	597	6
LONGLEAF PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
POND PINE	1667	299	299	101	242	186	268	111	92	41	26	0	2
SHORTLEAF PINE	199933	68663	40697	37499	27905	15182	6672	2504	683	190	81	37	0
SLASH PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
VIRGINIA PINE	561638	376840	236478	132438	80931	36695	13656	3632	794	128	33	13	0
OTHER YELLOW PINES	76453	19041	12680	14635	11133	8936	5501	2746	1002	440	79	52	0
TOTAL YELLOW PINES	1897048	765514	492636	293963	173809	90619	45938	20305	8641	3523	1246	699	8
OTHER SOFTWOODS:													
EASTERN WHITE PINE	140213	81523	24656	11919	7776	5348	3427	2602	1397	675	327	343	16
CYPRESS	2193	302	294	185	133	236	259	241	186	90	90	141	35
OTHER SOFTWOODS	288168	194551	60776	19556	7304	2736	1399	810	330	306	149	196	53
TOTAL OTHER SOFTWOODS	430574	276377	85926	31662	15215	8320	5085	3653	1913	1071	566	680	104
SOFT HARDWOODS:													
SWEETGUM	753389	548292	135297	48196	24280	12768	7067	3846	1784	929	468	443	29
YELLOW POPLAR	623495	342024	137675	58036	37902	28137	20682	13091	7483	3991	1891	1833	180
TUPELO AND BLACKGUM	690716	555140	76082	25413	14010	8892	4856	2616	1635	832	430	536	76
BAY AND MAGNOLIA	69109	46085	10798	6080	3092	1743	620	331	97	69	82	105	7
SOFT MAPLES	1477609	1101200	210540	75960	38026	22333	10606	5271	3341	1729	950	1061	125
OTHER SPECIES	272764	167206	55095	16849	13056	7282	4842	2733	1696	785	420	698	78
TOTAL SOFT HARDWOODS	3913252	2759967	597497	233134	130968	81133	49670	28088	16036	8335	4241	4676	495
OAKS:													
BLACK	218114	101218	39439	27706	17296	12839	9426	5564	3169	1647	920	808	82
CHESTNUT	493193	149954	120696	61247	53832	33896	20342	12848	8622	4862	2892	3373	455
LAUREL	6457	4069	1215	631	144	156	73	14	67	40	5	26	17
NORTHERN RED	250153	137361	39390	26836	16432	10986	8258	6061	3626	2215	1497	2117	360
SCARLET	268401	175012	67953	43198	29024	17805	9598	5842	2675	1167	533	363	21
SOUTHERN RED	170471	94947	36962	14376	9096	6129	3739	2925	1233	726	332	349	58
WATER	52835	38756	9145	3073	1794	436	318	156	78	32	32	22	1
WHITE	702193	327990	161992	80303	48794	32340	20072	12871	7733	3974	2136	2172	216
OTHER OAKS	141122	81847	21542	14810	8971	5434	3975	2433	993	682	410	539	86
SCRUB OAKS	29975	16725	8057	1826	496	362	92	12	0	15	0	0	0
TOTAL OAKS	2347914	1053969	504991	295798	185459	120381	74892	48726	28596	15360	8757	9749	1316
OTHER HARDWOODS:													
ASH	188303	120634	36490	14293	7346	3875	2687	1431	866	380	154	159	18
HICKORY	697827	416282	114906	51316	31093	19898	10785	6467	3386	1804	679	643	66
OTHER HARD HARDWOODS	1646678	1009310	291166	85235	44059	24681	13777	7652	4512	2752	1544	1770	220
TROPICAL AND MISC. SPP.	1276643	956477	239570	57066	16673	4957	1520	475	136	50	23	32	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	4109451	2502703	684132	207914	99131	53411	28769	16025	8902	4986	2400	2604	304
ALL SPECIES	12695839	7857440	2365121	1060771	604592	353761	223359	116797	64088	33275	17210	18408	2227

Table 28. Merchantable cubic volume of all live trees on commercial forest land, Virginia, by species and diameter class, 19[illegible]

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
							THOUSAND CUBIC FEET						
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	2220843	0	0	260525	341602	369143	396219	333634	244608	145543	71164	57533	1272
LONGLEAF PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
POND PINE	16774	0	0	299	1341	1669	3650	3380	3119	1421	1717	0	260
SHORTLEAF PINE	714577	0	0	96778	183589	167512	130972	70459	27127	9289	5095	3716	0
SLASH PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
VIRGINIA PINE	1728934	0	0	380384	541078	434105	245132	92994	26740	5691	1931	879	0
OTHER YELLOW PINES	397420	0	0	36957	61823	59084	45093	33130	33204	19766	4352	4009	0
TOTAL YELLOW PINES	5078938	0	0	774943	1129633	1081713	851272	582497	334794	181709	84255	66137	1555
OTHER SOFTWOODS:													
EASTERN WHITE PINE	308980	0	0	30164	48573	55996	55406	59764	43591	29197	17869	26027	2413
CYPRESS	91187	0	0	748	1034	2927	5262	7468	7553	4462	5413	11556	4744
OTHER SOFTWOODS	220975	0	0	42104	36254	24034	18235	18507	11041	13173	8050	18346	10642
TOTAL OTHER SOFTWOODS	621142	0	0	73016	85891	83957	78923	85759	62185	46749	31332	55931	17799
SOFT HARDWOODS:													
SWEETGUM	833035	0	0	103737	144227	147524	138900	110791	69763	47233	29341	36643	4676
YELLOW POPLAR	2264737	0	0	169027	244570	331324	390056	355500	277217	196065	115272	156374	29332
TUPELO AND BLACKGUM	514200	0	0	62637	78393	87581	79846	66132	50994	31116	16973	29800	8726
BAY AND MAGNOLIA	88706	0	0	14380	19017	16685	10836	8063	3094	2572	4785	6411	761
SOFT MAPLES	1245198	0	0	213250	221817	226930	168615	118247	100625	65590	45706	68797	15653
OTHER SPECIES	548290	0	0	49234	78175	77165	87075	68081	60441	35248	24787	53952	13692
TOTAL SOFT HARDWOODS	5494158	0	0	612265	786199	869209	875130	727334	562134	378126	238784	352137	72840
OAKS:													
BLACK	671152	0	0	75856	97173	129715	135918	131454	109936	71498	51666	61212	10724
CHESTNUT	2307682	0	0	205169	295574	334668	313071	266684	261081	188878	137484	231071	54322
LAUREL	19527	0	0	1487	994	1517	1266	345	2911	1606	487	2559	2833
NORTHERN RED	1131316	0	0	77504	100533	118172	142356	152182	123729	100215	85689	173943	57191
SCARLET	1019737	0	0	123049	178920	194416	166900	144376	98053	54323	29604	26913	3163
SOUTHERN RED	403467	0	0	33384	49967	62198	61160	69559	41858	32396	17687	26654	8404
WATER	39226	0	0	8208	10024	4805	5096	4173	2515	1484	1566	1210	145
WHITE	2374507	0	0	223818	296429	360186	360504	336246	276844	186202	123959	176533	33766
OTHER OAKS	425393	0	0	36217	49368	59262	66546	60750	34551	31788	24478	49117	13316
SCRUB OAKS	7536	0	0	2926	1484	2327	774	122	0	205	0	0	0
TOTAL OAKS	8595945	0	0	787618	1080466	1266966	1253555	1185691	947078	668595	472460	749412	183904
OTHER HARDWOODS:													
ASH	272103	0	0	36481	42199	41854	45909	35640	29300	17575	7668	12509	2968
HICKORY	1211265	0	0	131966	178921	212335	190240	171056	125059	89688	42264	58835	10901
OTHER HARD HARDWOODS	1604909	0	0	205041	249309	248608	223693	177794	144552	117116	82153	130674	25967
TROPICALS AND MISC. SPP.	267267	0	0	107297	78658	42272	20687	9758	3574	1979	975	2067	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	3355544	0	0	480785	549087	545069	480529	394248	302485	226360	133060	204085	39836
ALL SPECIES	23145297	0	0	2728627	3631276	3866514	3549409	2955729	2208676	1501539	959891	1427702	315934

SPECIES	ALL CLASSES	DIAMETER CLASS 2	4	6	8	10	12	14	16	18	20	22-28	30+
						THOUSAND CUBIC FEET							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	2929832	57405	236943	371639	416735	430599	453498	377656	275679	163588	79845	64423	1422
LONGLEAF PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
POND PINE	19712	14	263	383	1626	2204	4460	3309	3566	1623	1952	0	318
SHORTLEAF PINE	936140	14040	39881	131454	221376	218110	150072	80089	30666	10514	5757	4181	0
SLASH PINE	3	0	0	0	0	3	0	0	0	0	0	0	0
VIRGINIA PINE	2656065	123803	435194	504773	652209	509294	283597	106943	30725	6511	2206	1010	0
OTHER YELLOW PINES	495374	5321	23063	48216	73858	103597	98412	72570	38066	22673	4959	4637	0
TOTAL YELLOW PINES	7007123	200583	735344	1056665	1365598	1263804	990039	640567	378904	204909	94719	74251	1740
OTHER SOFTWOODS:													
EASTERN WHITE PINE	467178	10994	19471	40253	58609	66150	64736	69396	50451	33682	20627	30025	2784
CYPRESS	53360	145	408	1048	1328	3684	6505	9061	9186	5450	6532	14029	6484
OTHER SOFTWOODS	341483	32709	56121	63885	46161	29870	21641	21413	12666	14966	9167	20830	12054
TOTAL OTHER SOFTWOODS	872521	43848	76000	105186	106098	99704	92882	99870	72303	54098	36326	64884	21322
SOFT HARDWOODS:													
SWEETGUM	1246132	94572	136415	154571	180280	175259	161845	127699	79868	54005	33566	42564	5488
YELLOW POPLAR	2851870	84040	144598	226076	291795	382557	445114	402904	312933	220848	130033	176406	34566
TUPELO AND BLACKGUM	638620	104183	85708	90158	99681	107500	99543	80720	61784	37735	23412	37059	11337
BAY AND MAGNOLIA	132671	9881	11901	21019	23995	22884	13075	9668	3596	3254	5596	6966	836
SOFT MAPLES	2161015	267693	342029	304464	263311	279576	208507	143400	120582	78160	53952	81092	18249
OTHER SPECIES	771879	37645	70763	69804	97422	92694	103608	61037	70611	41220	28540	62560	15775
TOTAL SOFT HARDWOODS	8022387	598014	791414	866092	976484	1060470	1031892	845428	649374	435222	275099	406647	86251
OAKS:													
BLACK	1185950	22981	49708	113767	128427	164668	170364	163492	131009	88221	63926	76214	13873
CHESTNUT	3138071	32216	151901	296392	385543	422929	394605	357967	326114	235209	172225	291435	71535
LAUREL	22578	863	1223	2348	1349	2004	1613	435	3182	2011	509	3240	3801
NORTHERN RED	1514941	30237	45690	107181	130255	150115	178106	190166	154511	125326	106782	221050	75520
SCARLET	1405506	28225	75498	173944	230864	244352	208051	179270	121879	67409	37283	34732	3999
SOUTHERN RED	585359	21519	43299	54199	67508	79768	76282	86126	51369	39687	21819	32988	10795
WATER	71758	7915	10407	12780	13675	6285	6946	5289	3142	1843	1914	1502	160
WHITE	3298231	75341	161179	330496	389269	457328	451912	416530	343613	230795	154527	221231	44008
OTHER OAKS	591688	16537	25564	57754	66118	75487	83714	75933	42967	39261	30319	60761	17473
SCRUB OAKS	24072	4111	8023	4617	2098	2689	1685	267	0	582	0	0	0
TOTAL OAKS	11838354	239345	592492	1153480	1415106	1605625	1573178	1477477	1177786	830344	589304	943153	241164
OTHER HARDWOODS:													
ASH	395553	26153	34839	54890	53277	49491	54255	41581	33927	20277	9030	14450	3383
HICKORY	1783772	88012	140079	207180	237134	267174	233510	208970	152590	109491	51657	73466	14509
OTHER HARD HARDWOODS	2714335	309459	370291	274676	318479	311399	280800	221129	180567	145769	102624	164660	34285
TROPICALS AND MISC. SPP.	838637	188727	267786	156334	103158	53456	26194	12200	4524	2424	1238	2596	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	5732300	612351	832995	693280	712048	681520	594759	483880	371608	277961	164549	255172	52177
ALL SPECIES	33472685	1694041	3028245	3874703	4575334	4711123	4282750	3547222	2649975	1802534	1159997	1744107	402654

Table 30 — Merchantable green weight of all live trees on commercial forest land, Virginia, by species and diameter class, 1977

SPECIES	ALL CLASSES	DIAMETER CLASS											
		2	4	6	8	10	12	14	16	18	20	22-28	30+
	HUNDRED THOUSAND POUNDS												
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	1636532	0	0	196706	253511	273121	290840	243471	178488	135987	51760	41801	925
LONGLEAF PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
POND PINE	11997	0	0	218	960	1320	2745	2064	2275	1019	1234	0	202
SHORTLEAF PINE	502205	0	0	62374	127401	135258	94179	50574	19446	6666	3648	2659	0
SLASH PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
VIRGINIA PINE	1326942	0	0	321005	406150	322771	191966	85951	19603	4214	1430	647	0
OTHER YELLOW PINES	260823	0	0	22487	41360	57064	56050	42163	22507	13468	2959	2765	0
TOTAL YELLOW PINES	3738499	0	0	602792	829382	789534	625780	407223	242404	131354	61031	47872	1127
OTHER SOFTWOODS:													
EASTERN WHITE PINE	247000	0	0	20797	32513	36938	37459	40511	29367	19401	11760	16770	1484
CYPRESS	39332	0	0	385	577	1971	3795	5584	5807	3515	4282	9401	4015
OTHER SOFTWOODS	156466	0	0	34520	28379	18631	14029	14476	8624	10180	6203	13750	7674
TOTAL OTHER SOFTWOODS	442798	0	0	55702	61469	57540	55283	60571	43798	33096	22245	39921	13173
SOFT HARDWOODS:													
SWEETGUM	617787	0	0	79111	104502	107830	102082	82017	52082	35610	22320	28477	3756
YELLOW POPLAR	1609869	0	0	115064	167303	229562	276362	254776	200552	143040	84710	116144	22356
TUPELO AND BLACKGUM	348668	0	0	38312	48083	55577	52175	45906	37535	23655	14770	24620	8035
BAY AND MAGNOLIA	56684	0	0	8106	11390	11489	6645	5484	2188	2130	3636	5003	613
SOFT MAPLES	937650	0	0	158296	167936	173412	123281	68749	76473	50157	35021	52572	11749
OTHER SPECIES	371557	0	0	30928	49388	50324	56465	46148	42346	25342	16291	41021	11304
TOTAL SOFT HARDWOODS	3942215	0	0	429819	548604	628194	617010	523080	411176	279934	178748	267837	57813
OAKS:													
BLACK	779979	0	0	71771	89202	117676	122763	116523	92793	62222	44743	52849	9237
CHESTNUT	1520745	0	0	156241	225595	260491	241082	225495	206603	152870	112341	192045	45982
LAUREL	12585	0	0	1156	810	1245	1022	282	2063	1318	333	2077	2279
NORTHERN RED	933216	0	0	60601	81766	98445	116871	125596	102472	83246	71327	145152	47740
SCARLET	896552	0	0	107861	157506	172340	149074	126662	85073	46821	25436	23057	2722
SOUTHERN RED	333867	0	0	22234	35919	47714	52613	60190	36714	28871	15998	24991	6423
WATER	32011	0	0	6545	8116	3922	4136	3481	2105	1247	1323	1019	113
WHITE	1962616	0	0	171343	233908	292216	301974	262443	233835	156256	106039	152688	29912
OTHER OAKS	361931	0	0	26556	39111	49299	56269	52367	30296	28317	22009	45089	12618
SCRUB OAKS	8204	0	0	3414	1602	2120	764	116	0	186	0	0	0
TOTAL OAKS	7141706	0	0	627722	873537	1045670	1046770	993157	793954	563354	399549	638967	159026
OTHER HARDWOODS:													
ASH	174407	0	0	26741	28950	27308	28863	21876	17564	10260	4391	6915	1539
HICKORY	984671	0	0	97614	139115	173389	155757	140095	104122	75832	36164	51838	10145
OTHER HARD HARDWOODS	1382394	0	0	158017	207556	218080	196883	156643	126671	103423	73325	118029	23767
TROPICALS AND MISC. SPP.	194923	0	0	84162	55030	27771	15397	6935	2445	1306	623	1252	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	2736395	0	0	366534	430651	446548	396900	326149	250802	190823	114503	178034	35451
ALL SPECIES	18001613	0	0	2082569	2743643	2967486	2741743	2310180	1742134	1198561	776076	1172631	266590

SPECIES	CLASSES	2	4	6	8	10	12	14	16	18	20	22-28	30+
						HUNDRED THOUSAND POUNDS							
SOUTHERN YELLOW PINES:													
LOBLOLLY PINE	2136213	40782	151465	281039	369076	318592	332892	276105	201232	119128	58079	46797	1032
LONGLEAF PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
POND PINE	14075	11	172	278	1160	1557	3174	2369	2556	1163	1406	0	229
SHORTLEAF PINE	637330	11103	28829	84403	153579	157353	107923	57487	21989	7548	4123	2993	0
SLASH PINE	0	0	0	0	0	0	0	0	0	0	0	0	0
VIRGINIA PINE	2013777	90265	308192	427380	489503	378665	210526	79297	22754	4820	1632	743	0
OTHER YELLOW PINES	326439	3894	16339	29366	49381	66343	64022	48469	25803	15450	3375	3197	0
TOTAL YELLOW PINES	5127034	146055	504997	822466	1062693	922510	719337	463727	274334	148109	68615	53730	1261
OTHER SOFTWOODS:													
EASTERN WHITE PINE	313225	6020	12781	27758	39241	43629	43753	47018	33988	22409	13572	19344	1712
CYPRESS	49042	109	302	540	740	2481	4673	6775	7063	4292	5172	11413	5482
OTHER SOFTWOODS	264068	25022	41772	52393	36670	22567	16637	16744	9892	11606	7063	15609	8693
TOTAL OTHER SOFTWOODS	626335	33151	54855	80691	76051	68677	65063	70537	50943	38307	25807	46366	15887
SOFT HARDWOODS:													
SWEETGUM	944286	77989	112553	118357	130617	128106	118934	94540	59626	40709	25541	32906	4409
YELLOW POPLAR	2023192	60585	99373	153906	199620	265072	315395	288775	226389	161141	95546	131036	26352
TUPELO AND BLACKGUM	591261	33687	68478	55070	61111	68233	64974	56034	45504	28097	18259	30717	10497
BAY AND MAGNOLIA	65700	7124	8228	11637	14366	14067	8164	6574	2544	2415	4251	5450	678
SOFT MAPLES	1626924	200183	244274	225891	214464	213598	152423	107615	91651	59771	41343	62014	13697
OTHER SPECIES	529470	28679	52347	43987	61544	60451	67235	54480	49450	29621	21117	47538	13021
TOTAL SOFT HARDWOODS	5800833	458247	585253	609048	681724	749527	727125	608018	475164	322354	206057	309663	68653
OAKS:													
BLACK	1065153	21624	44764	107777	117901	149640	153868	144923	114753	76787	55358	65806	11952
CHESTNUT	2490827	29275	132627	225715	294221	329216	304007	261599	260578	190324	140769	242071	60425
LAUREL	18555	842	1116	1825	1103	1644	1301	356	2014	1650	416	2632	3059
NORTHERN RED	1256663	29394	41332	83757	105921	125045	146245	156957	127964	104104	88871	164346	62927
SCARLET	1240150	27241	68480	152480	203229	216607	185810	157261	105743	58102	32030	29750	3417
SOUTHERN RED	487793	20899	39134	35999	48496	61198	65871	74508	45053	35369	19736	30710	10820
WATER	60615	7716	9371	10178	11072	5128	5553	4411	2628	1550	1617	1266	125
WHITE	2725393	65344	150148	252909	307102	370999	378533	351582	290209	196137	132178	191297	38915
OTHER OAKS	563197	15073	29011	42393	52380	62803	70784	65454	37674	34967	27259	55788	16574
SCRUB OAKS	25423	4473	8021	5401	2264	2813	1663	259	0	529	0	0	0
TOTAL OAKS	9873689	221881	517004	918431	1143686	1325093	1313635	1237310	987216	699519	498234	803666	208214
OTHER HARDWOODS:													
ASH	265583	21346	28399	40309	36568	32295	34095	25508	20331	11830	5164	7985	1753
HICKORY	1464797	81271	122841	153118	184323	218173	191149	171683	127040	92561	44206	64724	13511
OTHER HARD HARDWOODS	2324777	261835	313200	212801	265086	272774	246217	194593	159142	128691	91586	148606	31244
TROPICALS AND MISC. SPP.	654209	156139	230576	122976	72179	35124	19495	8675	3093	1601	790	1573	0
PALMS	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OTHER HARDWOODS	4709366	522591	695016	529198	558158	558363	490956	400689	308606	234683	141746	222688	46508
ALL SPECIES	26136257	1381929	2357119	2959834	3480312	3624170	3316116	2760251	2096263	1442972	940459	1436313	340523

PROBLEMS AND POSSIBLE SOLUTIONS

This paper reports the best estimates of southeastern forest biomass that can be made at this time, but in many ways the estimates are not good enough. Inventory techniques used to obtain the reported information were designed primarily to estimate merchantable volumes. As a result, the errors associated with estimates of number of merchantable trees and their volumes are known and considered acceptable. Errors associated with volume and weight of unmerchantable trees and of portions of trees traditionally left in the woods are not known. Weight of shrubs, grasses, and forbs was not estimated because data were not available. Similarly, biomass in dead trees and downed trees was not estimated. Forest land that is classed as "unproductive" has been excluded from detailed inventories and is not represented here, nor is productive forest land which has been removed from commercial timber production, or land classed as "nonforest." As a result, the biomass totals reported here are incomplete, and the errors associated with the totals are unknown.

Although the totals reported here are of considerable interest, they cannot be fully analyzed without information on annual growth, annual removal, and natural loss of biomass. Furthermore, we think that information on conditions where the material occurs is very important. Some saplings, for example, occur as suppressed understories of stands that are ready for harvest. These trees may represent an excellent source of fuel if they cannot be used for conventional products. Other saplings are in young stands and represent prime growing stock for the future. Ways must be found to separate biomass that is ready for harvest from that which represents valuable growing stock.

It is important to recognize the relationship between shortages of fuel and interest in biomass data. Much of the demand for information on forest biomass can be traced to organizations or to individuals who hope to use wood for fuel. The demand for fuelwood is new and must be added to those for traditional forest products. In forest inventories, therefore, biomass data are no substitute for data that have been gathered for many years. Traditional forest industries will want to receive the same sorts of information they have always received. The demand for biomass information is essentially a new, additional demand.

Interest in biomass for fuel centers on material that is not utilized by traditional forest industries. Supposedly such material will be available at a low price because there will be relatively little competition for its use. Hence, it is most important in a biomass inventory to measure accurately the materials that have been ignored in traditional inventories—small trees, tops of large trees, stumps, rough and rotten trees, and dead trees.

Many actions will be needed to inventory and report southeastern biomass in the most useful ways. Some of the needs are listed below under three categories—coordination, research, and inventory.

COORDINATION

The need for information about biomass has been apparent for several years, and many experts are working in the field. Efforts should be coordinated to avoid duplication.

In 1979 the Southern Forest Biomass Working Group was formed under the leadership of the Utilization of Southern Timber Work Unit. The goals of the organization are:

1. Standardizing of tree component definitions.
2. Acceptance of standard approaches for sampling and weight estimation.
3. Accuracy standards of biomass estimation.
4. Agreement on major biomass variables and reporting methods.

RESEARCH

The equations used to generate biomass estimates for this report come from a database of over 4,000 trees, but many species had to be grouped because weight equations for some members of the group were unavailable. Another problem is the limited geographic basis of the 62 sample locations of the database trees for the broad regional application attempted here. Some obvious research needs are:

- Equations for predicting tree weights from tree diameters and heights for all southeastern species containing significant amounts of biomass.
- Improved equations for predicting weights of highly variable tree components such as crowns.
- Identification of geographic variations in weight relationships for important tree species in the South.
- Identification of variations in weight per cubic foot for various portions and components of trees.
- Methods for estimating foliage weight from the space it occupies. The volume of space occupied by crowns of sample trees is now being estimated by Southeastern Station inventory crews.
- Methods for estimating weight of shrubs, vines, grasses, and forbs from the space they occupy. Once again, inventory crews are already estimating space occupancy.
- Efficient plot designs for inventory of understory vegetation on forest land and all vegetation on nonforest land.
- Biomass growth and yield for all kinds of forest conditions and silvicultural treatments.
- In-depth analysis of the biomass resource to clarify potential for increasing utilization without seriously affecting traditional wood product supplies.
- Identification of geographic patterns in biomass distribution and availability for fuel.

1. Trees (all live trees 1.0 inch d.b.h. and larger)

Since much of the material to be inventoried has been ignored in the past, some obvious changes will be required:

1. Measurement of understory and lesser vegetation on all forest land.
2. Measurement of trees and other vegetation on nonforest land.
3. Determination of biomass growth and removals.
4. Determination of biomass utilization during harvesting and land clearing.

In response to the needs recognized here, we propose to inventory each of the items identified by the statewide biomass model listed below. We will retain detailed species, size, and quality information for all vegetation and fully describe and characterize many biotic, abiotic, and economically important site and stand variables so that the biomass data can be screened, sorted, aggregated, and analyzed in various ways.

STATEWIDE BIOMASS MODEL

Commercial Forest Land

I. Trees (1.0-inch d.b.h. and larger)
  A. Growing stock
    1. Wood and bark
      (a) Merchantable portion
      (b) Stumps, tops, and limbs
    2. Foliage
  B. Cull trees
    1. Wood and bark (total tree)
    2. Foliage
  C. Saplings
    1. Wood and bark (total tree)
    2. Foliage

II. Other biomass
  A. Seedlings
  B. Shrubs
  C. Vines
  D. Grasses
  E. Forbs

I. Trees (all live trees 1.0-inch d.b.h. and larger)
  A. Wood and bark (total tree)
  B. Foliage

II. Other biomass
  A. Seedlings
  B. Shrubs
  C. Vines
  D. Grasses
  E. Forbs

Unproductive Forest Land

I. Trees (all live trees 1.0-inch d.b.h. and larger)
  A. Wood and bark (total tree)
  B. Foliage

II. Other biomass
  A. Seedlings
  B. Shrubs
  C. Vines
  D. Grasses
  E. Forbs

Nonforest Lands (Associated Biomass)

I. Land use class
  A. Trees (all live trees 1.0-inch d.b.h. and larger)
    1. Wood and bark (total tree)
    2. Foliage
  B. Other biomass
    1. Seedlings
    2. Shrubs
    3. Vines
    4. Grasses
    5. Forbs

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KEYWORDS: Florida, Georgia, North Carolina, South Carolina, Virginia, forest inventory, fuelwood.

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Control of *Heterobasidion annosum* Colonization in Mechanically Sheared Slash Pine Stumps Treated with *Peniophora gigantea*

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Control of *Heterobasidion annosum* Colonization in Mechanically Sheared Slash Pine Stumps Treated with *Peniophora gigantea*

by Eldon W. Ross and Charles S. Hodges, Jr.[1]

ABSTRACT.–Heterobasidion annosum readily colonized slash pine stumps sheared by a mechanical tree harvester, but treatment with (1) a spore suspension of *Peniophora gigantea,* (2) a solution of borax (Polybor®), or (3) dry borax prevented natural colonization of stumps by *H. annosum.* Even in stumps artificially inoculated with *H. annosum,* surface treatment with *P. gigantea,* Polybor, or borax reduced the area of the stump colonized by *H. annosum* from 61 percent in the controls from 1 to 1.5 percent in the treatments. Efficacy of the stump protectants applied in a liquid permits development of an automated application system for mounting on mechanical harvesters.

Keywords: Mechanical tree harvester, *Fomes annosus,* root rot, biological control, tree disease control.

Mechanical tree harvesters are becoming increasingly opular in the Southern United States, both for thinnings nd for final harvests. In thinnings where risk of infection y *Heterobasidion annosum* (Fr.) Bref. is high, an autoated system for treating stump surfaces would be highly esirable. Currently, the only registered method for conolling this root pathogen is by applying dry technicalrade granular borax to the stump surface. A liquid would e much easier to apply with a machine, because it could be prayed through a hydraulic system.

The study described here was designed to test the effiacy against *H. annosum* of two liquid preparations–a olution of water-soluble borax (Polybor® U.S. Borax, isodium octaborate tetrahydrate)[2] and an aqueous spore uspension of *Peniophora gigantea* (Fr.) Massee, a biological ontrol agent already in use against *H. annosum* in England Greig and Burdekin 1970; Rishbeth 1963) and proved ffective in the United States (Driver and Ginns 1969; lodges 1964, 1970; Kuhlman and Hendrix 1964). Either of hese liquid preparations might be applied through a presurized hydraulic system. Efficacies were compared with hat of dry granular borax (sodium tetraborate decaydrate).

MATERIALS AND METHODS

The study was conducted in a 15-year-old slash pine lantation in Calhoun County, Florida. The plantation was commercially thinned with a mechanical tree harvester that shears the tree by hydraulically forcing a steel blade through the stem. Every third row of trees was completely removed along with selected trees in the remaining rows. Stumps, which were about 10 cm high, were treated immediately after the trees were sheared. A plot consisted of a series of 25 stumps receiving a single treatment. Treatments were randomly assigned to plots and were replicated three times. Six stump treatments were applied:

1. *P. gigantea* oidial suspension (100,000/ml H_2O)
2. *P. gigantea* oidial suspension (200,000/ml H_2O)
3. Polybor solution (22 g/l H_2O)
4. Polybor solution (44 g/l H_2O)
5. Dry granular borax
6. Control (no treatment)

An identical series of stumps, treated as above, was inoculated with a suspension of *H. annosum* conidia (100,000/ml H_2O) immediately before treatments were applied. In all, 900 stumps were included in this study.

P. gigantea cultures used to prepare oidial suspensions were supplied by Biological Consulting Associates, Raleigh, North Carolina. The live cultures containing approximately known numbers of spores were carried to the field in plastic petri dishes. The surface of the culture was flooded with a few ml of tapwater and rubbed gently with several layers of cheesecloth. The resulting suspension of oidia and mycelia was washed through a cheesecloth filter into a 10-l low-pressure garden sprayer. Tapwater was added in appropriate volume to prepare the correct concentration of spores. Conidial suspensions of *H. annosum* were prepared similarly except spores were washed from the culture aseptically.

All spore suspensions were sprayed on the stump surfaces to the point of runoff. An average stump with a 25- to 30-cm diameter usually required no more than 15 ml of spore suspension for adequate coverage. An application of

[1] Director, Southeastern Forest Experiment Station, Asheville, IC, and Research Plant Pathologist, Pacific Southwest Forest Experiment Station, Honolulu, HI. When this research was done the uthors were Plant Pathologists at the Southeastern Forest Experient Station.

[2] Mention of a particular product should not be taken as enorsement by the Forest Service or the U.S. Department of Agriulture.

100,000 spores/ml placed 2,000 to 3,000 spores per cm^2 of stump surface. The Polybor solutions were applied with similar sprayers and techniques. Dry borax was applied from a container with a perforated top until a light, even coating was achieved.

All treatments were applied within a 3-day period in December. Each morning, beginning at 7 a.m. on the days treatments were applied, spore traps (Ross 1973) were deployed for a 2-hour period to determine the abundance of natural inoculum of *H. annosum* and *P. gigantea.*

Three months after treatment, the tops of all the stumps were severed with a chain saw and isolations made to determine fungal colonization. Each stump was severed approximately 4 cm below its surface. The freshly cut surface of this disk was sprayed with a solution of Alizarin Red S indicator dye to estimate the area of the stump at that point which was colonized by *P. gigantea* (Blakeslee and Stambaugh 1974; Lindgren 1955). A second disk, approximately 7 cm thick, was severed from the same stump. It was placed in a 1 percent (v/v) solution of sodium hypochlorite for 10 minutes to control surface contamination, and then split in quarters. Wood cores from the disk were removed aspetically with an increment hammer and placed in a selective medium (Kuhlman and Hendrix 1962) in 9-cm plastic petri dishes for incubation. Five wood cores were removed approximately 2 cm below the upper surface of the disk (7 to 8 cm below surface of original stump) along each face of the quarter. The cultures were incubated at room temperature (25°C) for 7 days. Growth of *P. gigantea* and *H. annosum* from each core was recorded. Area of the stump colonized was computed on the basis of the colonized proportion of the 40 cores from that stump.

RESULTS

During the early morning of the days when stumps were treated, viable spores of *H. annosum* were deposited on traps at a rate of $2/dm^2/h$, but no viable spores of *P. gigantea* were trapped.

All stumps inoculated with both concentrations of *P. gigantea* spores were very heavily colonized by *P. gigantea.* None of the stumps artificially inoculated with *P. gigantea,* but naturally inoculated by *H. annosum,* were colonized by *H. annosum.* Only 10 and 15 percent of the stumps artificially inoculated with the two spore concentrations of *P. gigantea* and *H. annosum* were colonized by *H. annosum.* Dry granular borax and both concentrations of Polybor were equally effective in controlling initial colonization by *H. annosum* (table 1).

Isolation data indicate that 7 to 8 cm below the stump surface the area colonized by *P. gigantea* was about the same after treatment with 100,000/ml or 200,000/ml suspensions of *P. gigantea* spores (88 and 87 percent, respectively). This large area colonized by *P. gigantea* was confirmed by the Alizarin Red S indicator dye test on the stump disk approximately 3 cm above the point where the isolations were made. The indicator dye test suggested that

Table 1.—Percentage of slash pine stumps colonized by *Heterobasidion annosum* after treatment with *Peniophora gigantea,* Polybor®, and dry granular borax

Treatment	Source of *H. annosum*	
	Natural inoculation	Artificial inoculation
	..... *Percent*	
P. gigantea:		
100,000/ml	0	15
200,000/ml	0	10
Polybor®:		
22g/l	0	4
44g/l	0	1
Dry borax	0	1
Control	54	97

virtually 100 percent of the cross sections of the stump at these levels was colonized. The isolation data also strongly suggest *P. gigantea,* when artificially inoculated, can severely limit the ability of *H. annosum* to colonize the stump. For the two concentrations of *P. gigantea* applied, the areas colonized by *H. annosum* were 1 and 2 percent in stumps artificially inoculated by both *H. annosum* and *P. gigantea,* while 84 and 85 percent of the areas were colonized by *P. gigantea.* Sixty-one percent of the area in untreated controls was colonized by *H. annosum* (table 2).

Dry granular borax and both concentrations of Polybor were very effective in controlling colonization by *H. annosum.* In no instance where stumps were treated with Polybor or dry granular borax was the average area of stumps colonized by *H. annosum* greater than 1 percent (table 2).

DISCUSSION

The excellent colonization of slash pine stumps by *P. gigantea* was effective in preventing natural infection of the stumps by *H. annosum.* Even in stumps artificially inoculated with *H. annosum* at spore concentrations many times probable natural deposition (Ross 1973) during the period of high susceptibility to infection (Ross 1968), *P. gigantea* greatly reduced colonization of the stumps by *H. annosum.*

Even in stumps with *H. annosum,* only a very small percentage of the area was colonized. Close examination revealed that passage of the shearing blade through the wood created a series of vertically oriented cracks approximately 1 cm apart and 1 cm deep across the stump surface. Materials applied in aqueous suspension or solution were immediately carried at least 1 cm into the stump. This penetration probably explains why such uniform colonization was achieved by *P. gigantea.*

Although natural inoculum of *P. gigantea* was not recorded on spore traps deployed on the days stumps were

Table 2.–Mean percentage of slash pine stump area colonized by *Heterobasidion annosum* and *Peniophora gigantea* when treated with *Peniophora gigantea,* Polybor®, and dry granular borax

Treatment	Natural inoculation with *H. annosum*		Artificial inoculation with *H. annosum*	
	Colonized by		Colonized by	
	P. gigantea	*H. annosum*	*P. gigantea*	*H. annosum*
	Percent			
P. gigantea:				
100,000/ml	88	0	85	2
200,000/ml	87	0	84	1
Polybor®:				
22g/l	<1	0	1	<1
44g/l	<1	0	1	<1
Dry borax	<1	0	1	<1
Control	10	7	<1	61

reated, low levels of natural colonization (average 10 percent of stump area) by *P. gigantea* occurred after 3 months. t appears that stumps are susceptible to colonization by *P. gigantea* several days after they are cut and probably onger than the period of high susceptibility to *H. annosum.* Since 7 percent of the area of the same stumps was colonized by natural inoculum of *H. annosum,* our results support earlier findings which suggest that present levels of natural inoculum of *P. gigantea* cannot be relied on to adequately control stump colonization by *H. annosum* (Blakeslee and Stambaugh 1974).

Both concentrations of Polybor were effective in controlling colonization (an average of 1 percent or less of the stump area) of sheared stumps by *H. annosum.* Under these test conditions, Polybor was as effective as dry granular borax, whose effectiveness in controlling stump colonization by *H. annosum* is well known (Hodges 1970). Our experience with Polybor at these concentrations suggests that in low-pressure sprayers it may tend to crystallize in the nozzle and impede the flow of the solution onto the stump. However, clogging probably would not occur in high-pressure sprayers that would be used on mechanical harvesters. Additional studies of application techniques may be necessary to determine whether clogging is likely to be a problem.

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Heterobasidion annosum readily colonized slash pine stumps sheared by a mechanical tree harvester, but treatment with (1) a spore suspension of *Peniophora gigantea,* (2) a solution of borax (Polybor®), or (3) dry borax prevented natural colonization of stumps by *H. annosum.*

KEYWORDS: Mechanical tree harvester, *Fomes annosus,* root rot, biological control, tree disease control.

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Multiresource Inventories--Forest Biomass in South Carolina

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Multiresource Inventories--Forest Biomass in South Carolina

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Abstract.–South Carolina's 12.5 million acres of timberland support 1,014 million tons of forest biomass, or an average of 81.1 tons per acre. This total quantity exceeds the green weight of conventional growing stock by 57 percent. Over the next decade, at least 16.7 million tons of forest biomass could be harvested annually without adversely affecting timber supplies. In terms of weight, this amount of energy wood is roughly equivalent to the total green weight of industrial roundwood products harvested in South Carolina in 1977.

Keywords: Forest biomass, growing stock, timberland, management class.

INTRODUCTION

In the forestry community, resurection of wood as a major fuel fosters oth interest and concern. There is conderable interest in any opportunity to id timberland of vast quantities of ood and bark in low-quality trees. here is also concern that large-scale se of wood for fuel would jeopardize upplies of growing stock counted on for ther products. Much depends upon hether wood is viewed as a temporary or enewable source of energy. Although his uncertainty makes it difficult to ifferentiate between energy wood and rowing stock, it is imperative that the uantity, composition, distribution, and rospective availability of total forest iomass be evaluated.

The first multiresource inventory f South Carolina's forests, completed n 1978, provided a wealth of relevant ata (McClure, Cost, and Knight 1979). Statewide timber evaluation focused rimarily on the volume of growing-stock imber on commercial forest land (Knight nd McClure 1979). Volume of growing tock is the quantity of sound wood in ll growing-stock trees 5.0 inches dimeter at breast height (d.b.h.) and arger from a 1-foot stump to a minimum 4.0-inch top diameter outside bark (d.o.b.) of the central stem and forks. Growing-stock trees are live trees of commercial species that meet specified standards for sawtimber or will likely meet such standards when they reach minimum sawtimber size--9.0 inches d.b.h. for softwoods and 11.0 inches d.b.h. for hardwoods. Because of a growing interest in forest biomass as a source of energy, there is a need to evaluate the amount of additional wood and bark on commercial forest land. Commercial forest land includes all forest land producing or capable of producing crops of industrial wood and not withdrawn from timber use.

In this evaluation, we define forest biomass as the green weight of aboveground wood and bark (excluding foliage) in all live trees 1.0 inch d.b.h. and larger growing on commercial forest land. Foliage includes leaves, needles, buds, fruit, twigs, and lateral limbs smaller than 0.5 inch in diameter. One of the primary objectives of this study is to compare total biomass as defined with green weight of conventional growing stock, including bark. Another objective is to quantify and focus attention on major prospective sources of energy wood in South Carolina--on

sources that could be harvested in harmony with conventional forestry practices for enhancing future timber growth. Finally, as a byproduct, measures of total forest biomass open up new opportunities for refining and studying forest yields, timber utilization, and successional trends.

METHODS

In the 1978 multiresource inventory of South Carolina's forests, sample trees were counted by species, size, and quality class. These sample counts were expanded to represent the total population of trees on lands classified as commercial forest. Volume prediction equations, developed from detailed measurements of more than 34,000 trees throughout the Southeast since 1963, provided reliable estimates of aboveground volume (Cost 1978). Studies by the Utilization of Southern Timber Research Work Unit at the Forestry Sciences Laboratory in Athens, Georgia, provided the vital linkage between volume and weight (Saucier 1979).

In the 1978 inventory, the trees were measured and forest conditions were classified at 4,038 ground sample locations systematically distributed throughout the State's 12.5 million acres of commercial forest. Information developed from these measurements and classifications provides the primary basis for evaluating forest biomass.

In the statewide timber evaluation, South Carolina's forests were divided into six broad management classes: (1) nonstocked forest, (2) pine plantation, (3) natural pine, (4) oak-pine, (5) upland hardwood, and (6) lowland hardwood. Nonstocked forest is commercial timberland less than 16.7 percent stocked with growing-stock trees. The other broad management classes are based on forest type determined by the stocking of all live trees. All stands where pines make up the plurality of the stocking are classed as either pine plantation or natural pine. Stand origin distinguishes between these two classes. Where there is evidence of planting or artificial regeneration, the stand is classified as a pine plantation. Oak-pine is the classification assigned to stands with the plurality of the stocking in hardwoods but in which pines account for 25 to 50 percent. In all other stands, hardwoods and cypress constitute a plurality of the stocking, and forest type distinguishes between upland and lowland hardwood. Oak-hickory types are classed as upland hardwood, and oak-gum-cypress and elm-ash-cottonwood types as lowland hardwood.

Because forest types are based on the stocking of all live trees, except those overtopped, rather than on growing-stock trees, the broad management classes are even more meaningful in the evaluation of biomass. In this study of biomass, the broad management class "nonstocked forest" used in the timber evaluation was distributed among the other classes based on forest type. Although these stands contain insufficient growing stock to be considered stocked, many contain substantial amounts of biomass in rough and rotten trees.

Acreage of commercial forest land by broad management classes was broken down into stand-age classes. Since very little merchantable-size timber accrues in a stand before age 15 and many pine stands are managed on 30-year rotations, 15-year age classes were selected for this analysis. We had major difficulties in determining a meaningful age in some natural stands. Often natural stands are a mixture of older residual trees from a former stand and younger trees established following the most recent harvest or disturbance. In these cases, field crews recorded the average age of trees of common origin which made up a plurality of the stocking as long as they were of sufficient number to form a manageable stand for timber production--normally 60 percent or more of the minimum number required for full stocking. Where the number of trees of common origin were insufficient for a manageable stand, the age was based on all trees present. This approach affects interpretation of empirically determined biomass yields presented in this paper.

Finally, the acreage within each broad management class was further broken down by site and stocking classes. The stocking classes were based on all

live trees rather than on growing stock. Average green weight of forest biomass per acre was compiled for each subdivision. The weight equations used were sensitive to species, d.b.h., and total height. There may be additional variation in weight attributable to geographical differences, stand origin (planted vs. natural), or tree section, but these are ignored in this paper.

RESULTS AND DISCUSSION

A compilation of acreage of commercial forest land, by broad management and stand age classes, provides a good basis for examining the quantity, composition, distribution, and prospective availability of forest biomass in South Carolina (table 1). Pine stands are concentrations in age classes between 15 and 45 years old. Many of these pine stands were established on old fields during a period of extensive cropland retirement, especially between 1945 and 1965. These "old-field" stands of pine are relatively free from hardwood competition.

Since about 1965, the acreage of idle cropland in South Carolina rotating back to forest has declined sharply. Most often, southern yellow pines are the pioneering tree species in the natural succession of idle fields back to forest. Tree planting on old fields also decreased sharply after termination of the Conservation Reserve Soil Bank Program in the early 1960's. The acreage figures for pine plantation and natural pine in table 1 reflect some of the results of these changes in land use.

The greatest concentration of oak-pine and upland hardwood stands is between ages 30 and 60. Many of these stands are on sites which previously supported pine, but where the pine was not adequately regenerated at time of harvest. Lowland hardwood stands account for half of all stands 60 years and older. Most of these stands are on the coastal plain in swamps and on the floodplains of rivers and streams. Because of seasonal and in some cases year-round water problems, many of these stands are difficult to harvest. Over the years, the large and good-quality trees have been high-graded from these stands, leaving the smaller and poorer quality trees.

Total forest biomass exceeded the weight of conventional growing stock by 57 percent.

One of the primary objectives of this study is to compare the green weight of total forest biomass, as defined in this report, with the green weight of conventional growing stock, including bark. Weight of conventional growing stock is the weight of wood and bark associated with the bole portion of growing-stock trees 5.0 inches d.b.h. and larger, from a 1-foot stump to a 4.0-inch top d.o.b. Across the 12.5 million acres classed as commercial forest land, green weight of conventional growing stock averaged 51.4 tons per acre (table 2). Green weight of total forest biomass averaged 81.1 tons per acre, or 57 percent more (table 3).

In the younger age classes, cull trees left as residuals from former stands and saplings account for most of the additional weight. In the older age classes, most of the difference is attributed to cull trees and the stumps, tops, and limbs of growing-stock trees. By broad management class, differences between average weight of conventional growing stock and total forest biomass per acre were largest in hardwood stands. In upland hardwood stands, with all ages grouped, average weight of total forest biomass exceeded average weight of conventional growing stock by more than 30 tons per acre, or 72 percent. In lowland hardwood stands, the difference averaged more than 50 tons per acre.

Tables 2 and 3 provide measures of the average accumulation of biomass within each broad management class over time, without any consideration of differences in site and stocking. As one would expect, conventional growing stock accumulates somewhat faster in pine stands, especially pine plantations, than in hardwood stands. In plantations, control over species composition and spacing permits a shortening of the time required to grow a stand to

Table 1.—Area of commercial forest land, by broad management class and stand age class, South Carolina, 1978

Broad management class	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Thousand acres					
Pine plantation	1,361.5	581.6	687.8	83.7	5.2	3.2
Natural pine	4,209.4	514.3	1,127.2	1,544.4	729.9	293.6
Oak-pine	1,718.5	310.3	305.4	542.5	368.4	191.9
Upland hardwood	2,945.3	555.8	415.2	782.0	823.6	368.7
Lowland hardwood	2,268.2	166.4	211.6	507.4	538.0	844.8
All classes	12,502.9	2,128.4	2,747.2	3,460.0	2,465.1	1,702.2

Table 2.—Average green weight of conventional growing stock[a] per acre of commercial forest land, by broad management class and stand age class, South Carolina, 1978

Broad management class	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons					
Pine plantation	32.6	4.9	49.1	82.2	(b)	(b)
Natural pine	55.0	12.8	40.6	64.9	76.1	79.9
Oak-pine	40.9	12.3	26.5	45.5	55.5	69.1
Upland hardwood	42.0	7.5	19.8	43.0	60.1	76.7
Lowland hardwood	76.4	15.1	31.2	60.1	76.9	109.3
All classes	51.4	9.4	37.3	56.6	67.8	92.7

[a]Includes wood and bark between a 1-foot stump and 4-inch top d.o.b. in growing-stock trees 5.0 inches d.b.h. and larger.
[b]Sample was too small to provide a reliable estimate.

merchantable size for production of conventional products. These factors translate into significant economic advantages in pine production and support the preferences for pine evidenced in most intensive timber management practices in South Carolina.

What one might not expect is the evidence in table 3 that some hardwood stands, especially lowland hardwood stands, just about keep pace with the more intensively managed pine plantations in production of total forest biomass. Through age 45, which is as far as the data permit comparisons, forest biomass appears to accumulate almost as fast in lowland hardwood stands as in pine plantations. Admittedly, more of the lowland hardwood stands are on good sites than are pine plantations--35 percent as compared to 25 percent. There is less difference in the stocking of all live trees between these two management classes. In each, more than 70 percent of the acres are fully stocked.

The relatively low production of forest biomass indicated for oak-pine and upland hardwood management classes can be attributed in part to the origin of many of these stands. Many of these acres support sparsely stocked conditions on upland sites left following the harvesting of pine stands. Less than 60 percent of the upland hardwood acreage is fully stocked with live trees. By broad management class, across all age classes, average weight of forest biomass ranged from a low of 49.4 tons per acre in pine plantations to a high of 126.5 tons per acre in lowland hardwood stands. The low overall average for pine plantations is attributed to the high proportion (90 percent) of these stands less than 30 years old. More than 80 percent of the lowland hardwood stands were 30 years of age or older.

About 30 tons of standing biomass per acre are left following harvesting.

Average green weight of forest biomass per acre also varied by recent past treatment or disturbance. At each sample location, inventory field crews noted the primary treatment or disturbance in evidence which had occurred between 1968 and 1978. Results of these classifications were reported by broad management and ownership classes (Knight and McClure 1979, table VI). As part of this evaluation of forest biomass, these acreage estimates were recompiled; ownership class was eliminated, and the acreage classed as nonstocked forest was redistributed among the other broad management classes, based on forest type (table 4).

All kinds of final harvesting, including clearcutting, seed tree, salvage, and high-grading, were grouped. Over the 10.4-year remeasurement, more than 2.0 million acres of commercial forest land were so harvested and retained in commercial forest. Thus, the rate of final harvest averaged almost 200,000 acres per year, excluding commercial thinnings, other intermediate cutting, and land clearing. Green weight of forest biomass on harvested commercial forest land averaged 30.7 tons per acre (table 5).

Since all of these treatments occurred during the remeasurement period, one can assume that measures of average biomass per acre reflect the quantities some 5 years after the treatment in cases of harvesting, thinning, and planting. Also keep in mind that the broad management classes describe the forest type at the time of the new inventory in 1978 rather than at the time of treatment. By broad management class, average weight of forest biomass left following harvesting ranged from 5.9 tons per acre in pine plantations to 57.4 tons per acre in lowland hardwood stands. The low average for plantations reflects areas clearcut, site prepared, and planted within the 10-year period. The high average for lowland hardwood reflects quantities of forest biomass left following the high-grading of these stands within the same period. When these extremes were eliminated, biomass in other recently harvested stands averaged about 30 tons per acre in live trees. A large proportion of this biomass was in rough trees, rotten trees, and small trees left standing when the stands were harvested. If tables 3 and 5 are compared, it becomes apparent that these residual trees also influenced the determination of stand

Table 3. Average green weight of forest biomass per acre of commercial forest land, by broad management class and stand age class, South Carolina, 1978

Broad management class	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons					
Pine plantation	49.4	12.0	73.0	107.0	(a)	(a)
Natural pine	78.7	24.0	64.4	91.0	103.1	104.6
Oak-pine	67.6	22.6	50.3	75.8	89.5	102.4
Upland hardwood	72.1	17.7	43.9	76.5	98.1	118.2
Lowland hardwood	126.5	29.4	72.8	103.5	126.1	173.2
All classes	81.1	19.3	62.5	87.6	104.4	141.5

[a]Sample was too small to provide a reliable estimate.

Table 4.—Area of commercial forest land, by recent past treatment or disturbance and broad management class, South Carolina, 1978

Recent past treatment or disturbance[a]	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Thousand acres					
Harvesting	2,046.1	386.7	397.7	282.6	654.6	324.5
Commercial thinning	670.5	195.2	300.5	69.6	53.8	51.4
Artificial planting	136.8	113.5	–	13.1	7.4	2.8
Natural disturbance	944.3	206.8	408.2	117.2	126.9	85.2
Other[b]	2,419.8	153.3	1,075.4	362.9	603.5	224.7
None	6,285.4	306.0	2,027.6	873.1	1,499.1	1,579.6
All stands	12,502.9	1,361.5	4,209.4	1,718.5	2,945.3	2,268.2

[a]Primary treatment or disturbance of the stand between 1968 and 1978.
[b]Includes cleaning, release, grazing, draining, prescribed burning, site preparation, and other miscellaneous treatments.

Table 5.—Average green weight of forest biomass per acre of commercial forest land, by recent past treatment or disturbance and broad management class, South Carolina, 1978

Recent past treatment or disturbance[a]	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
			Tons			
Harvesting	30.7	5.9	34.7	30.4	29.9	57.4
Commercial thinning	81.2	72.1	90.0	62.9	72.0	98.4
Artificial planting	14.6	16.7	–	5.7	(b)	(b)
Natural disturbance	83.0	76.9	86.8	69.9	86.3	93.1
Other[c]	77.8	68.5	77.9	73.2	71.6	107.6
None	99.9	74.0	84.5	78.2	89.8	146.4
All stands	81.1	49.4	78.7	67.6	72.1	126.5

[a]Primary treatment or disturbance of the stand between 1968 and 1978.

[b]Sample was too small to provide a reliable estimate.

[c]Includes cleaning, release, grazing, draining, prescribed burning, site preparation, and other miscellaneous treatments.

age, as discussed under Methods in this paper. For example, in table 3, weight of forest biomass averaged 19.3 tons per acre across all stands less than 15 years old. Yet in table 5, weight of forest biomass on acres harvested between 1968 and 1978 averaged 30.7 tons per acre. Obviously, the stand age assigned to some of the acreage harvested was older than 15 years because many older residual trees were present.

Also keep in mind that the 30 tons per acre of forest biomass left following harvesting did not include the material in stumps, tops, and limbs of cut trees left as logging residue. Even in the pine plantations, substantial quantities of these residues are commonly pushed into windrows where there is intensive site preparation following harvesting. Both standing residues and logging residues are primary sources of energy wood.

About one-third of the forest biomass was in stands where prospective energy wood could be harvested in harmony with conventional forestry practices.

Perhaps one of the most meaningful ways to look at the distribution of forest biomass in South Carolina is by the treatment opportunity classes reported by Knight and McClure (1979, table VII). In addition to recording recent past treatments and disturbances, field crews noted obvious management opportunities for increasing timber growth at each sample location. A recompilation of the acreage, eliminating ownership class and idle cropland and redistributing nonstocked forest among the other management classes, provides another basis for examining the distribution of forest biomass (table 6).

Almost 2.1 million acres of commercial forest land in South Carolina were too poorly stocked with acceptable trees to manage for timber production unless they are regenerated. These acres supported an average of 44.1 tons of forest biomass per acre (table 7).

Table 6.—Area of commercial forest land, by treatment opportunity class and broad management class, South Carolina, 1978

Treatment opportunity class	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Thousand acres					
Salvage	110.9	29.4	54.4	6.2	5.6	15.3
Harvest	621.3	3.3	149.3	56.5	110.3	301.9
Commercial thinning	472.4	158.2	245.8	12.0	7.4	49.0
Other stand improvement	864.0	26.3	285.5	182.3	215.5	154.4
Stand conversion	494.9	6.1	58.8	106.8	244.5	78.7
Regeneration	2,072.1	58.4	383.2	363.4	814.3	452.8
None[a]	7,440.6	1,079.8	2,992.4	949.5	1,427.2	991.7
Adverse sites	426.7	–	40.0	41.8	120.5	224.4
All stands	12,502.9	1,361.5	4,209.4	1,718.5	2,945.3	2,268.2

[a]Immature stands sufficiently stocked with growing-stock trees relatively free from damage or competition.

Table 7.—Average green weight of forest biomass per acre of commercial forest land, by treatment opportunity class and broad management class, South Carolina, 1978

Treatment opportunity class	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Tons					
Salvage	85.5	57.0	71.0	63.6	123.8	185.9
Harvest	166.6	(a)	126.7	148.9	142.8	197.8
Commercial thinning	131.6	114.0	130.7	120.6	157.8	191.6
Other stand improvement	67.3	47.7	53.7	56.8	66.2	109.7
Stand conversion	40.9	67.7	38.6	39.9	36.4	56.1
Regeneration	44.1	19.5	26.4	45.3	42.2	64.8
None[b]	82.4	40.8	82.1	74.7	87.5	128.7
Adverse sites[c]	131.3	–	86.3	93.1	98.9	163.5
All stands	81.1	49.4	78.7	67.6	72.1	126.5

[a]Sample was too small to provide a reliable estimate.
[b]Immature stands adequately stocked with growing-stock trees relatively free from damage or competition.

Mostly, the forest biomass on these poorly stocked acres consisted of rough, rotten, and other low-quality trees with only a scattering of growing-stock trees. Altogether, these acres supported about 9 percent of the total forest biomass in the State. Furthermore, most of this biomass could be removed and used for energy without adversely affecting prospective timber supplies.

Much of this regeneration opportunity is in hardwood stands that have been severely high-graded, leaving a residual cover of rough and rotten trees. It also includes acreage where pine stands have been harvested without any site preparation or other steps taken to regenerate the stands. Tolerant, low-grade hardwoods in the understory of pine stands often are released by the harvesting and impede the establishment and development of reproduction. This accumulation of poorly stocked forest land included a large backlog of these conditions as well as stands recently harvested. Although the more practical and efficient practice is to remove this low-quality timber at time of harvest, a growing demand for energy wood could provide a second opportunity to rid the timberland of much of this inhibiting vegetation.

An additional 0.5 million acres supported manageable stands but were expected to contribute very little net annual growth unless converted to species more suitable to the sites. Stand conversion was the treatment opportunity assigned to this acreage. This opportunity included some pine stands where the existing species had been particularly susceptible to a disease, such as fusiform rust. Shortleaf pine on a littleleaf site is another example. Most of the stand conversion opportunity, however, was where upland hardwoods had replaced pines following harvesting on poor, dry sites. Across all management classes within the stand conversion opportunity, forest biomass averaged 40.9 tons per acre.

Some 0.6 million acres supported mature and overmature stands with low growth, high mortality, and a high risk of deterioration unless harvested and regenerated. This acreage, which could be harvested, supported an average of 166.6 tons of forest biomass per acre. If these stands are harvested as they have been in recent years, some 30 tons of forest biomass will be left per acre in live standing trees. These residuals, together with the material in stumps, tops, and limbs left as logging residue, represent another primary source of energy wood that could be exploited without adversely affecting prospective timber supplies. Of course, the presence of an overmature stand often indicates that the owner does not choose to harvest it. Since this estimate of harvest opportunity excludes adverse sites, any availability problem would have to be attributed to owner intent. Since forest land is frequently bought and sold, owner intent to avoid harvest is often temporary.

Another 0.1 million acres supported merchantable-size timber so seriously damaged by disease, insects, fire, weather, or other agents that salvage and regeneration should be considered. These stands contained an average of 85.5 tons per acre of forest biomass plus an undetermined amount of wood and bark in dead trees. Finally, more than 1.3 million acres were classed either as offering a commercial thinning opportunity or as needing other stand improvement such as cleaning and release.

About two-thirds of the forest biomass in South Carolina was either in stands exhibiting no obvious treatment opportunity or in stands growing on sites where steep slopes or water severely limit harvesting and management. More than 7.4 million acres supported immature stands judged to be adequately stocked with growing-stock trees relatively free from damage or competition. On these acres, forest biomass averaged 82.4 tons per acre. An additional 0.4 million acres supported stands on slopes 40 percent or steeper or on wet sites with year-round water problems. On these adverse sites, forest biomass averaged 131.3 tons per acre. Over the past 10 years, only 14 percent of the sites classed as adverse experienced any cutting or treatment, while there was evidence of cutting or treatment on more than 40 percent of the remaining acreage. Thus, large quantities of prospective energy wood cannot be regarded

as readily available on adverse sites.

About one-third of the forest biomass in South Carolina was in stands where prospective energy wood could be harvested in harmony with conventional forestry practices for enhancing future timber growth. Although approximately one-third of the forest biomass on commercial forest land was determined to be in stands offering opportunities for harvesting or treatment from a silvicultural standpoint, this proportion should not be misinterpreted as an estimate of energy wood. In many of the treatments, a large proportion of the forest biomass would be left. An examination of the distribution of forest biomass by tree class, component, and species group provides additional insight about the amount of forest biomass that could be removed without adversely affecting timber supplies.

Rough and rotten trees account for 16 percent of the total forest biomass.

Altogether, South Carolina's 12.5 million acres of commercial forest land supported 1,014 million tons of forest biomass in 1978. Growing-stock trees accounted for 84 percent of this forest biomass (table 8). The remaining 16 percent was in trees which failed to meet minimum standards for growing stock because of species, poor form, roughness, or excessive amounts of internal rot. Theoretically, 16 percent of the forest biomass on South Carolina's timberland could be removed without adversely affecting existing and prospective supplies of sawtimber. Half of the forest biomass in rough and rotten trees occurred in the bole sections of trees 5.0 inches d.b.h. and larger. The remaining half was in saplings, stumps, tops, and limbs.

In addition to the 16 percent of forest biomass in rough and rotten trees, another 14 percent was in stumps, tops, and limbs of growing-stock trees 5.0 inches d.b.h. and larger. Although conventional estimates of growing stock also exclude this material, it becomes available at time of harvest. Since this material would normally not be available prior to harvest, the percentage of forest biomass in stumps, tops, and limbs of growing-stock trees in table 8 probably overstates the amount of this kind of material available at any given time. Another 7 percent was in growing-stock saplings and should not be counted in estimates of energy wood.

Table 8 also points out the relative differences between conventional growing stock and total forest biomass among the major species groups. For example, yellow pines accounted for almost half the total volume of growing stock but less than 40 percent of total forest biomass. In the evaluation of forest biomass, hardwoods take on an added significance.

Over the next 10 years, at least 16.7 million tons of forest biomass could be harvested annually without adversely affecting timber supplies.

If a few reasonable assumptions are superimposed onto the findings of this study, an estimate of the amount of forest biomass that could be harvested annually in South Carolina evolves. The 2.1 million acres of poorly stocked timberland classified as offering a regeneration opportunity is the primary source of energy wood which could be harvested without adversely affecting prospective timber supplies for industrial products. These acres supported an average of 44.1 tons of forest biomass per acre. If 10 percent of this acreage was cleared each year and an average yield of 40 tons per acre is assumed, some 8.3 million tons of energy wood could be harvested annually from these lands over the next decade.

The 200,000 acres of timberland harvested annually are a second major source of prospective energy wood. Based on this study, some 30 tons per acre of forest biomass are left standing on these acres following harvest. An earlier study provided an independent estimate of these living residues expressed in cubic volume of wood (Welch 1980). A rough conversion of Welch's

Table 8.–Green weight and percentage distribution of forest biomass on commercial forest land, by tree class and component and species group, South Carolina, 1978

Tree class and component	All species	Species group				
		Yellow pines	Other softwoods	Soft hardwoods	Oaks	Other hardwoods
	Percent of green weight					
Growing stock:						
Bole	63.4	76.6	66.6	56.7	56.0	39.8
Stumps, tops, and limbs	13.6	13.9	16.9	12.0	16.0	9.7
Saplings	7.0	6.3	9.7	8.0	6.7	7.0
Total	84.0	96.8	93.2	76.7	78.7	56.5
Rough and rotten trees:						
Bole	8.0	1.9	4.0	12.8	10.9	15.9
Stumps, tops, and limbs	2.6	0.5	1.4	3.7	3.9	5.7
Saplings	5.4	0.8	1.4	6.8	6.5	21.9
Total	16.0	3.2	6.8	23.3	21.3	43.5
All classes	100.0	100.0	100.0	100.0	100.0	100.0
Green weight (million tons)	1,014.0	401.6	31.5	289.5	212.1	79.3

data provides a more conservative estimate--about 24 tons per acre. If the conservative yield of 24 tons per acre is assumed, 4.8 million tons of additional energy wood could be harvested annually from these living residues. Furthermore, Welch's study provided an estimate of logging residues--again expressed in cubic volume of wood. These logging residues convert to about 18 tons per acre, or another 3.6 million tons of prospective energy wood. These estimates of logging residue should not be confused with those developed in the timber evaluation, which included only the residues from the merchantable bole of growing-stock trees.

Based on these assumptions, at least 16.7 million tons of energy wood could be harvested annually over the next 10 years without adversely affecting timber supplies and in harmony with conventional forestry practices. The green weight of this amount of energy wood is roughly equivalent to the total green weight of the output of industrial roundwood products in South Carolina in 1977. Implied is an assumption that there has been no significant change in the large backlog of poorly stocked acreage offering a regeneration opportunity between 1978 and now.

Measures of total forest biomass open up new opportunities for studying successional trends, forest yields, and timber utilization.

The percentage distribution of forest biomass by species varies significantly by broad management class and to some extent by stand age (table 9). As noted previously, a large proportion of the pine stands, both planted and natural, between 15 and 30 years old were established on old fields. Yellow pines accounted for a significantly higher proportion of the biomass in these stands than in the pine stands less than 15 years old. More of these younger pine stands were established on cutover forest land; therefore, a higher proportion of their biomass was in hardwoods. Even with the most intensive site preparation of cutover forest land, it is difficult for foresters to remove hardwood rootstocks to the extent achieved by years of crop cultivation. Table 9 also provides evidence that pine biomass expressed as a percentage of total biomass declines in the oak-pine and other hardwood management classes as stands grow older, reflecting natural succession from pine to hardwood.

The distribution of forest biomass by diameter class within each broad management and age class provides additional measures of the accumulation of biomass over time (table 10). As noted earlier, there is evidence that lowland hardwood stands almost keep pace with the more intensively managed pine plantations in production of total forest biomass--at least up to about age 45. Between ages 30 and 45, about 70 percent of the biomass in pine plantations was in trees 9.0 inches d.b.h. and larger. Between these same ages, about 67 percent of the biomass in lowland hardwood stands was in trees 9.0 inches d.b.h. and larger. Unlike the pine plantations, a significant proportion of the biomass in large trees in the lowland hardwood stands as well as in other natural stands was in residual trees left following the harvesting of former stands. This fact also accounts for the large percentage of forest biomass in large trees in young natural stands in table 10.

Finally, within each management class, we examined the production and distribution of forest biomass in South Carolina by using the conventional determinants of timber yields: site, stocking, and age. These study results are presented in two series of tables as an appendix to this report (tables 11 to 20). Tables 11 to 15 show the distribution of acreage within each broad management class, by site, stocking, and age classes. Tables 16 to 20 show the average green weight of forest biomass per acre for each of these area classifications.

The site classes are those used in the timber evaluations. Good sites are those capable of producing 85 or more cubic feet of timber growth per acre annually in fully stocked natural stands. Medium sites are those capable of

Table 9.–Percentage distribution of the average green weight of forest biomass per acre of commercial forest land, by broad management class and species group and stand age class, South Carolina, 1978

Broad management class and species group	All age classes	Stand age class (years)				
		0–14	15–29	30–44	45–59	60+
				Percent		
Pine plantation:						
Yellow pines	92	88	94	91	–	–
Other softwoods	–	1	–	2	–	–
Oaks	3	4	2	2	–	–
Other hardwoods	5	7	4	5	–	–
All species	100	100	100	100	–	–
Natural pine:						
Yellow pines	81	76	82	81	80	78
Other softwoods	1	3	1	1	1	2
Oaks	8	10	7	7	9	10
Other hardwoods	10	11	10	11	10	10
All species	100	100	100	100	100	100
Oak-pine:						
Yellow pines	40	51	44	39	37	37
Other softwoods	2	2	1	3	1	2
Oaks	29	16	27	31	30	29
Other hardwoods	29	31	28	27	32	32
All species	100	100	100	100	100	100
Upland hardwood:						
Yellow pines	8	18	11	8	7	7
Other softwoods	1	–	–	1	1	1
Oaks	47	39	49	49	48	42
Other hardwoods	44	43	40	42	44	50
All species	100	100	100	100	100	100
Lowland hardwood:						
Yellow pines	4	9	6	5	4	2
Other softwoods	8	2	4	6	5	11
Oaks	18	28	18	17	19	18
Other hardwoods	70	61	72	72	72	69
All species	100	100	100	100	100	100

Table 10.–Percentage distribution of the average green weight of forest biomass per acre of commercial forest land, by broad management class and tree diameter and stand age class, South Carolina, 1978

Broad management class and tree diameter (inches)	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
			Percent			
Pine plantation:						
1.0- 4.9	14	40	12	5	–	–
5.0- 8.9	49	49	53	25	–	–
9.0-12.9	30	8	31	41	–	–
13.0+	7	3	4	29	–	–
All classes	100	100	100	100	–	–
Natural pine:						
1.0- 4.9	12	26	18	11	9	8
5.0- 8.9	27	35	39	27	19	12
9.0-12.9	31	21	28	33	32	27
13.0+	30	18	15	29	40	53
All classes	100	100	100	100	100	100
Oak-pine:						
1.0- 4.9	16	27	25	16	13	10
5.0- 8.9	25	30	36	29	23	15
9.0-12.9	24	21	21	28	26	21
13.0+	35	22	18	27	38	54
All classes	100	100	100	100	100	100
Upland hardwood:						
1.0- 4.9	14	28	27	17	10	8
5.0- 8.9	24	28	35	30	22	15
9.0-12.9	24	20	20	26	26	21
13.0+	38	24	18	27	42	56
All classes	100	100	100	100	100	100
Lowland hardwood:						
1.0- 4.9	10	22	32	11	9	7
5.0- 8.9	16	24	28	22	18	11
9.0-12.9	23	19	18	29	25	19
13.0+	51	35	22	38	48	63
All classes	100	100	100	100	100	100

producing 50 to 85 cubic feet, and poor sites are those capable of producing 20 to 50 cubic feet. The stocking classes are based on all live trees rather than growing stock. Fully stocked stands are those 100 percent or better stocked with all trees based on the same stocking standard used in the timber evaluation. Medium-stocked stands are those 60 to 100 percent stocked with all live trees, and poorly stocked stands are those less than 60 percent stocked with all live trees. As would be expected, the results show site and stocking to be important determinants of forest biomass production.

SUMMARY

Several conclusions can be drawn from a study of the quantity, composition, distribution, and prospective availability of total forest biomass on commercial forest land in South Carolina in 1978:

- South Carolina's 12.5 million acres of timberland supported 1,014 million tons of forest biomass, or an average of 81.1 tons per acre. This total quantity exceeds the green weight of conventional growing stock by 57 percent.
- Wood and bark in saplings, rough and rotten trees, and in the stumps, tops, and limbs of growing-stock trees 5.0 inches d.b.h. and larger account for this additional forest biomass.
- About 16 percent of the total forest biomass was in rough and rotten trees and could be removed without adversely affecting existing and prospective supplies of sawtimber. Another 14 percent was in the stumps, tops, and limbs of growing-stock trees 5.0 inches d.b.h. and larger and would normally not be available prior to harvest. Another 7 percent was in growing-stock saplings and should not be counted in estimates of energy wood.
- About one-third of the total forest biomass was in stands where prospective energy wood could be harvested in harmony with conventional forestry practices for enhancing future timber growth. The remaining two-thirds was either in stands exhibiting no obvious treatment opportunity or in stands on sites where steep slopes or water severely limit harvesting and management.
- Almost 2.1 million acres of commercial forest land were too poorly stocked with acceptable trees to manage for timber production unless regenerated. These ported about 9 percent of the total forest biomass. Most of this biomass could be removed and used for energy without adversely affecting prospective timber supplies.
- On the average, about 200,000 acres of timberland are harvested annually in South Carolina and retained in commercial forests. This average excludes commercial thinnings, other intermediate cutting, and land clearings. Forest biomass left in standing trees following harvest averaged approximately 30 tons per acre. From an earlier study, it was estimated that an additional 18 tons per acre in stumps, tops, and limbs of the cut trees are left as logging residues. Prospectively, these living and logging residues are primary sources of energy wood.
- When a few reasonable assumptions are superimposed onto these findings, it is estimated that at least 16.7 million tons of forest biomass could be harvested annually in South Carolina over the next decade without adversely affecting timber supplies. The green weight of this amount of energy wood is roughly equivalent to the total green weight of the output of industrial roundwood products in South Carolina in 1977.
- Conventional growing stock accumulates somewhat faster in pine stands, especially pine plantations, than in hardwood stands. In production of total forest biomass, lowland hardwood stands just about keep pace with the more intensively managed pine plantations, at least up to age 45.

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Appendix

Table 11.– Area of commercial forest land supporting pine plantations, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Thousand acres					
Good sites:						
Fully stocked	280.7	74.4	175.4	30.9	–	–
Medium stocked	48.0	10.7	26.0	11.3	–	–
Poorly stocked	8.9	–	8.9	–	–	–
All stands	337.6	85.1	210.3	42.2	–	–
Medium sites:						
Fully stocked	628.8	324.8	274.1	21.5	5.2	3.2
Medium stocked	176.5	84.0	81.5	11.0	–	–
Poorly stocked	40.2	14.8	22.5	2.9	–	–
All stands	845.5	423.6	378.1	35.4	5.2	3.2
Poor sites:						
Fully stocked	95.3	39.9	52.5	2.9	–	–
Medium stocked	60.2	19.7	37.3	3.2	–	–
Poorly stocked	22.9	13.3	9.6	–	–	–
All stands	178.4	72.9	99.4	6.1	–	–
All sites:						
Fully stocked	1,004.8	439.1	502.0	55.3	5.2	3.2
Medium stocked	284.7	114.4	144.8	25.5	–	–
Poorly stocked	72.0	28.1	41.0	2.9	–	–
All stands	1,361.5	581.6	687.8	83.7	5.2	3.2

Table 12.—Area of commercial forest land supporting natural pine stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0–14	15–29	30–44	45–59	60+
	Thousand acres					
Good sites:						
Fully stocked	734.5	51.9	172.2	297.5	160.2	52.7
Medium stocked	223.0	8.1	63.3	96.6	45.0	10.0
Poorly stocked	4.8	4.8	–	–	–	–
All stands	962.3	64.8	235.5	394.1	205.2	62.7
Medium sites:						
Fully stocked	1,871.5	257.6	590.9	659.3	285.2	78.5
Medium stocked	509.4	35.5	115.1	207.8	90.5	60.5
Poorly stocked	149.6	42.9	29.5	47.1	28.0	2.1
All stands	2,530.5	336.0	735.5	914.2	403.7	141.1
Poor sites:						
Fully stocked	400.1	70.1	94.1	118.6	66.3	51.0
Medium stocked	166.6	17.2	28.7	51.3	36.1	33.3
Poorly stocked	149.9	26.2	33.4	66.2	18.6	5.5
All stands	716.6	113.5	156.2	236.1	121.0	89.8
All sites:						
Fully stocked	3,006.1	379.6	857.2	1,075.4	511.7	182.2
Medium stocked	899.0	60.8	207.1	355.7	171.6	103.8
Poorly stocked	304.3	73.9	62.9	113.3	46.6	7.6
All stands	4,209.4	514.3	1,127.2	1,544.4	729.9	293.6

Table 13.—Area of commercial forest land supporting oak-pine stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Thousand acres					
Good sites:						
Fully stocked	243.9	46.7	29.6	77.6	58.6	31.4
Medium stocked	100.9	7.6	11.5	31.6	24.8	25.4
Poorly stocked	6.3	–	3.0	–	3.3	–
All stands	351.1	54.3	44.1	109.2	86.7	56.8
Medium sites:						
Fully stocked	692.5	183.6	108.7	215.0	142.9	42.3
Medium stocked	261.3	14.0	62.2	99.9	49.1	36.1
Poorly stocked	38.7	5.0	3.0	9.6	13.0	8.1
All stands	992.5	202.6	173.9	324.5	205.0	86.5
Poor sites:						
Fully stocked	217.9	44.1	50.2	59.1	41.6	22.9
Medium stocked	136.9	9.3	37.2	46.7	21.2	22.5
Poorly stocked	20.1	–	–	3.0	13.9	3.2
All stands	374.9	53.4	87.4	108.8	76.7	48.6
All sites:						
Fully stocked	1,154.3	274.4	188.5	351.7	243.1	96.6
Medium stocked	499.1	30.9	110.9	178.2	95.1	84.0
Poorly stocked	65.1	5.0	6.0	12.6	30.2	11.3
All stands	1,718.5	310.3	305.4	542.5	368.4	191.9

Table 14.--Area of commercial forest land supporting upland hardwood stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
			Thousand acres			
Good sites:						
Fully stocked	396.3	77.2	35.9	101.2	129.3	52.7
Medium stocked	181.9	15.8	26.0	59.8	33.5	46.8
Poorly stocked	28.6	10.4	3.5	4.7	4.4	5.6
All stands	606.8	103.4	65.4	165.7	167.2	105.1
Medium sites:						
Fully stocked	1,093.1	246.2	134.2	284.6	320.2	107.9
Medium stocked	583.2	58.7	56.7	168.1	215.7	84.0
Poorly stocked	134.8	59.6	18.1	30.9	23.8	2.4
All stands	1,811.1	364.5	209.0	483.6	559.7	194.3
Poor sites:						
Fully stocked	274.2	46.5	67.4	75.0	39.7	45.6
Medium stocked	186.7	17.1	52.4	51.3	42.2	23.7
Poorly stocked	66.5	24.3	21.0	6.4	14.8	--
All stands	527.4	87.9	140.8	132.7	96.7	69.3
All sites:						
Fully stocked	1,763.6	369.9	237.5	460.8	489.2	206.2
Medium stocked	951.8	91.6	135.1	279.2	291.4	154.5
Poorly stocked	229.9	94.3	42.6	42.0	43.0	8.0
All stands	2,945.3	555.8	415.2	782.0	823.6	368.7

Table 15.—Area of commercial forest land supporting lowland hardwood stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Thousand acres					
Good sites:						
Fully stocked	587.2	32.9	23.9	167.6	153.8	209.0
Medium stocked	194.7	12.5	25.1	70.9	55.3	30.9
Poorly stocked	13.8	2.4	2.3	2.4	3.3	3.4
All stands	795.7	47.8	51.3	240.9	212.4	243.3
Medium sites:						
Fully stocked	889.7	72.5	60.4	144.4	198.0	414.4
Medium stocked	305.2	20.4	28.3	65.7	80.6	110.2
Poorly stocked	51.5	16.0	8.5	9.4	9.6	8.0
All stands	1,246.4	108.9	97.2	219.5	288.2	532.6
Poor sites:						
Fully stocked	140.6	3.4	41.9	15.2	24.5	55.6
Medium stocked	62.2	3.1	12.0	23.6	10.2	13.3
Poorly stocked	23.3	3.2	9.2	8.2	2.7	–
All stands	226.1	9.7	63.1	47.0	37.4	68.9
All sites:						
Fully stocked	1,617.5	108.8	126.2	327.2	376.3	679.0
Medium stocked	562.1	36.0	65.4	160.2	146.1	154.4
Poorly stocked	88.6	21.6	20.0	20.0	15.6	11.4
All stands	2,268.2	166.4	211.6	507.4	538.0	844.8

Table 16.—Average green weight of forest biomass per acre of commercial forest land supporting pine plantations, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons					
Good sites:						
Fully stocked	88.6	26.2	105.8	141.2	—	—
Medium stocked	55.2	11.6	65.5	72.8	—	—
Poorly stocked	45.5	—	45.5	—	—	—
All stands	82.7	24.4	98.3	122.9	—	—
Medium sites:						
Fully stocked	46.1	10.8	78.9	125.0	(a)	(a)
Medium stocked	32.2	8.1	51.9	70.7	—	—
Poorly stocked	16.3	9.7	18.4	(a)	—	—
All stands	41.8	10.2	69.5	100.7	(a)	(a)
Poor sites:						
Fully stocked	27.5	8.6	41.8	(a)	—	—
Medium stocked	22.3	11.9	26.5	(a)	—	—
Poorly stocked	4.5	1.7	8.3	—	—	—
All stands	22.8	8.2	32.8	(a)	—	—
All sites:						
Fully stocked	56.2	13.2	84.4	129.0	(a)	(a)
Medium stocked	34.0	9.1	47.8	67.5	—	—
Poorly stocked	16.1	5.9	21.9	(a)	—	—
All stands	49.4	12.0	73.0	107.0	(a)	(a)

[a]Sample was too small to provide a reliable estimate.

Table 17.–Average green weight of forest biomass per acre of commercial forest land supporting natural pine stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
				Tons		
Good sites:						
Fully stocked	128.3	48.3	106.8	139.9	148.4	150.8
Medium stocked	94.5	8.2	75.7	100.6	113.9	137.3
Poorly stocked	(a)	(a)	–	–	–	–
All stands	119.8	39.8	98.4	130.2	140.9	148.6
Medium sites:						
Fully stocked	78.3	26.5	64.0	93.7	108.6	115.8
Medium stocked	66.9	23.8	46.0	70.9	78.3	101.6
Poorly stocked	26.9	2.5	28.7	36.5	42.6	75.4
All stands	73.0	23.2	59.8	85.6	97.2	109.1
Poor sites:						
Fully stocked	53.4	26.2	35.9	64.7	66.7	79.6
Medium stocked	43.8	5.7	41.8	40.1	61.6	51.3
Poorly stocked	18.3	1.9	24.1	18.0	24.6	(a)
All stands	43.8	17.5	34.4	46.2	58.7	66.8
All sites:						
Fully stocked	87.2	29.4	69.5	103.3	115.6	115.8
Medium stocked	69.5	16.6	54.5	74.5	84.1	88.9
Poorly stocked	22.3	2.3	26.2	25.7	35.4	51.8
All stands	78.7	24.0	64.4	91.0	103.1	104.6

[a]Sample was too small to provide a reliable estimate.

Table 18.—Average green weight of forest biomass per acre of commercial forest land supporting oak-pine stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
				Tons		
Good sites:						
Fully stocked	105.5	24.0	83.3	110.7	129.6	190.4
Medium stocked	92.8	(a)	62.0	94.6	100.4	115.0
Poorly stocked	(a)	—	(a)	—	(a)	—
All stands	100.6	25.2	73.5	106.0	118.0	156.6
Medium sites:						
Fully stocked	67.8	21.6	57.8	82.7	100.0	109.8
Medium stocked	61.9	23.4	46.3	65.4	75.9	74.6
Poorly stocked	24.5	(a)	(a)	27.7	21.1	37.9
All stands	64.6	21.2	53.2	75.7	89.3	88.4
Poor sites:						
Fully stocked	49.4	29.7	35.5	50.5	69.4	79.1
Medium stocked	38.9	4.4	29.2	41.0	54.7	49.8
Poorly stocked	29.8	—	—	(a)	27.6	(a)
All stands	44.5	25.3	32.8	45.4	57.8	63.8
All sites:						
Fully stocked	72.3	23.3	55.9	83.5	101.9	128.7
Medium stocked	61.8	20.0	42.2	64.2	77.6	80.2
Poorly stocked	27.1	(a)	(a)	24.6	27.0	42.2
All stands	67.6	22.6	50.3	75.8	89.5	102.4

[a]Sample was too small to provide a reliable estimate.

Table 19.–Average green weight of forest biomass per acre of commercial forest land supporting upland hardwood stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
				Tons		
Good sites:						
Fully stocked	103.9	25.2	63.7	104.1	141.1	155.3
Medium stocked	81.7	15.2	75.5	78.6	85.5	108.9
Poorly stocked	52.3	4.6	(a)	(a)	(a)	(a)
All stands	94.8	21.6	65.6	93.0	127.6	135.8
Medium sites:						
Fully stocked	78.2	21.5	48.2	91.0	105.5	129.9
Medium stocked	76.2	19.9	53.7	71.1	88.8	108.5
Poorly stocked	24.5	2.5	28.0	42.9	49.5	61.5
All stands	73.5	18.1	47.9	81.0	96.7	119.8
Poor sites:						
Fully stocked	46.1	19.7	33.0	36.4	71.2	86.2
Medium stocked	43.3	3.6	28.8	44.4	50.7	88.2
Poorly stocked	12.4	1.8	9.2	(a)	25.2	–
All stands	40.8	11.6	27.9	39.3	55.2	86.9
All sites:						
Fully stocked	79.0	22.0	46.2	85.0	112.1	126.8
Medium stocked	70.8	16.0	48.2	67.8	82.9	105.5
Poorly stocked	24.5	2.6	17.4	40.7	41.7	142.4
All stands	72.1	17.7	43.9	76.5	98.1	118.2

[a]Sample was too small to provide a reliable estimate.

Table 20.—Average green weight of forest biomass per acre of commercial forest land supporting lowland hardwood stands, by site, stocking, and stand age classes, South Carolina, 1978

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
				Tons		
Good sites:						
Fully stocked	147.7	33.2	69.9	127.5	154.1	186.2
Medium stocked	88.8	52.0	74.0	79.4	98.8	118.9
Poorly stocked	24.8	(a)	(a)	(a)	(a)	(a)
All stands	131.2	36.5	69.4	112.6	137.7	175.5
Medium sites:						
Fully stocked	150.2	26.3	92.5	121.6	140.2	195.0
Medium stocked	87.3	30.6	72.9	74.3	84.3	111.4
Poorly stocked	26.2	11.9	(a)	37.7	43.9	(a)
All stands	129.6	25.0	79.6	103.9	121.3	175.3
Poor sites:						
Fully stocked	119.6	(a)	77.0	83.4	117.7	163.3
Medium stocked	61.3	(a)	55.2	51.1	70.4	89.1
Poorly stocked	16.9	(a)	22.4	(a)	(a)	—
All stands	93.0	44.3	64.9	55.6	96.9	149.0
All sites:						
Fully stocked	146.6	31.0	83.1	122.9	144.4	189.7
Medium stocked	84.9	36.5	70.0	73.2	88.8	111.0
Poorly stocked	23.5	9.9	16.5	30.7	33.6	35.3
All stands	126.5	29.4	72.8	103.5	126.1	173.2

[a]Sample was too small to provide a reliable estimate.

Knight, Herbert A.; McClure, Joe P.
Multiresource inventories–forest biomass in South Carolina. Res. Pap. SE-230. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1981. 27 p.

South Carolina's 12.5 million acres of timberland support 1,014 million tons of forest biomass, or an average of 81.1 tons per acre. This total quantity exceeds the green weight of conventional growing stock by 57 percent. Over the next decade, at least 16.7 million tons of forest biomass could be harvested annually without adversely affecting timber supplies. In terms of weight, this amount of energy wood is roughly equivalent to the total green weight of industrial roundwood products harvested in South Carolina in 1977.

KEYWORDS: Forest biomass, growing stock, timberland, management class.

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Research Paper SE-231

An Evaluation of the Carbon Balance Technique for Estimating Emission Factors and Fuel Consumption in Forest Fires

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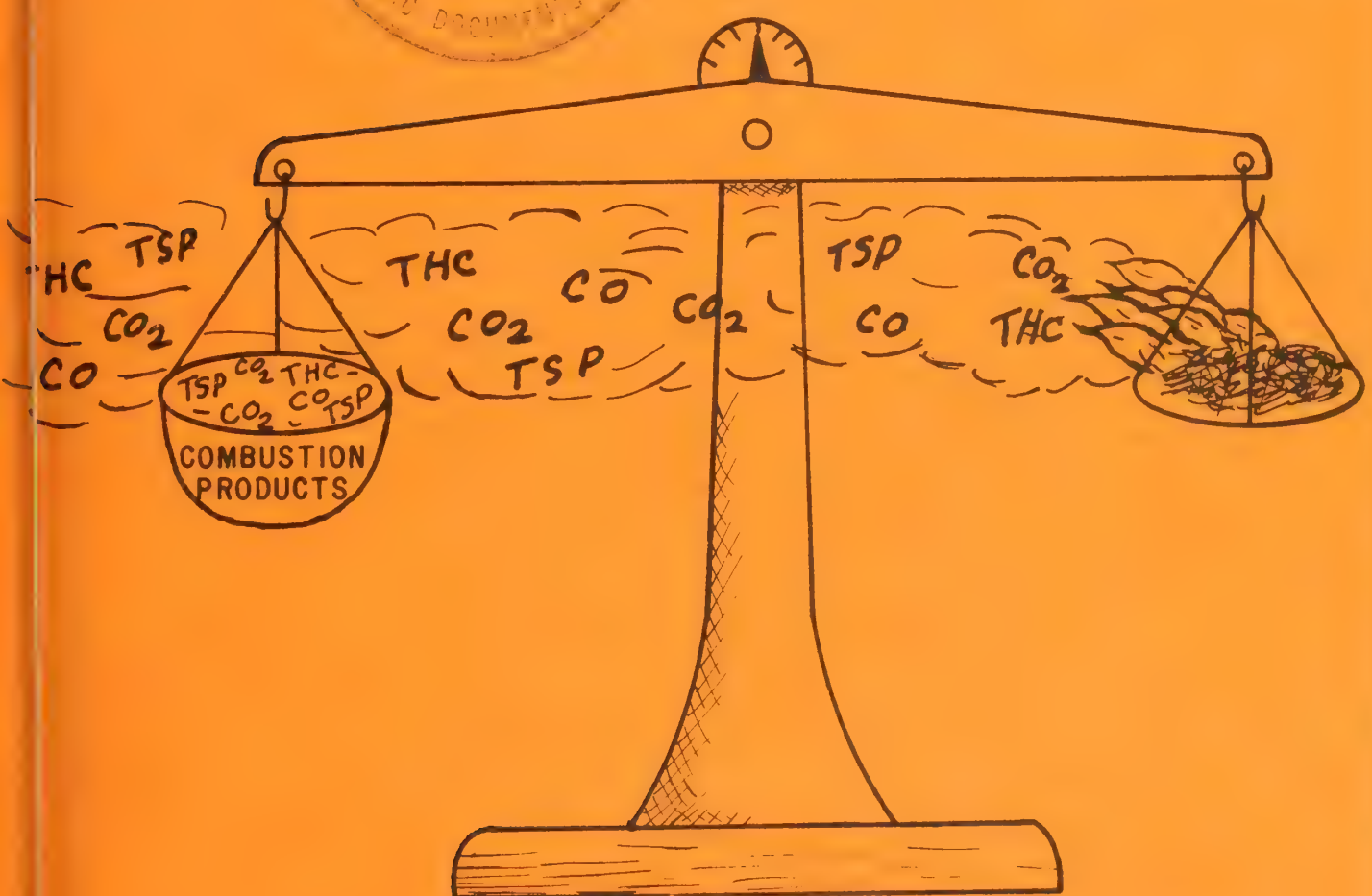

July 1982
Southeastern Forest Experiment Station
Asheville, North Carolina

An Evaluation of the Carbon Balance Technique for Estimating Emission Factors and Fuel Consumption in Forest Fires

by

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ABSTRACT.—Eighteen experimental fires were used to compare measured and calculated values for emission factors and fuel consumption to evaluate the carbon balance technique. The technique is based on a model for the emission factor of carbon dioxide, corrected for the production of other emissions, and which requires measurements of effluent concentrations and air volume in the plume. The maximum percent difference in values was about 15 percent. These differences followed the carbon balance percent differences closely, which indicates that field application of the technique should succeed to the extent that all carbon can be accounted for in sampling.
Keywords: Plume concentrations, laboratory fires, forest fire smoke, smoke management.

One of the problems addressed by research in forest fire behavior and smoke management is to minimize the production of undesirable emissions. Progress toward this goal depends, in part, upon development of practical methods for estimating forest fire emissions. In most of the previous research, emission factors[1] have been computed from measurements of mass concentration and fuel consumption. This approach is usually time consuming because fuels must be sampled before and after every burn. Also, because of the variability in natural fuels, some error is often introduced due to inadequate sampling.

An alternative method involves the principle of conservation of carbon atoms in the original fuel. This carbon balance technique is based on a combustion reaction involving production of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (THC), and particulate matter (TSP). The method seems well suited to forest fire applications in that both emission factor and fuel consumption estimates can be made without pre- and post-burn sampling of fuels.

Previous work utilizing the carbon balance technique is not extensive. Boubel and others (1969) were able to account for 99 ± 10 percent of the carbon in the original fuel while measuring emissions during laboratory burns of grasses from the Willamette Valley in Oregon. The technique was used by Goss and Miller (1973) to calculate particulate matter emission factors for burns of rice-field residue, and by Darley and others (1973) for agricultural and forest residues. Malte (1975) studied emissions data for burning Douglas-fir and larch slash fuels from laboratory and field studies. He combined carbon dioxide and particulate matter concentrations with a carbon balance approach to determine particulate matter, carbon dioxide, and carbon monoxide emission factors. Ward and others[2] used data collected on a single fire in southeastern Georgia to compare particulate emission factors measured by the following four independent methods: (a) aircraft sampling with a nephelometer, (b) aircraft sampling with particle counters, (c) surface sampling with filters, and (d) surface sampling with grab bags for use with a carbon balance technique. Emission factors obtained from all four methods were in substantial agreement. The carbon balance subsequently was used in field studies by Ward and others (1980). Vines and others (1971) and Evans and others (1976) assumed that amounts of CO, THC, and TSP produced by controlled burns in western Australia are negligible when compared with the CO_2 produced. They estimated the TSP emission factor by using measured concentrations of TSP and CO_2 in the plume and an emission factor for CO_2 of 1,830 g/kg (obtained from a chemical equation for complete combustion of the fuel). Whether carbonaceous products other than CO_2 can be ignored for purposes of estimating emission factors and fuel consumption in field burns is of practical interest and has provided much of the motivation for the work reported in this paper.

The present study is concerned with the feasibility of using concentration measurements of gaseous and particulate emissions for computing emission factors and fuel consumption in laboratory and field burns. It is assumed

[1] An emission factor for a given effluent is the mass of the effluent produced by a fire per mass of fuel consumed.

[2] Ward, D. E.; Nelson, R. M., Jr.; Adams, D. F. Forest fire smoke plume documentation. Pap. 79-6.3. Presented at the 72nd Annual Meeting of the Air Pollution Control Association; 1979 June 24–29; Cincinnati, OH. 24 p.

that the mass of all carbon-bearing effluents can be adequately accounted for by sampling the combustion products CO_2, CO, THC, and TSP. A model for the CO_2 emission factor is derived from a carbon balance and tested with experimental data from slash pine (*Pinus elliottii* Engelm.) needle beds burned in the Southern Forest Fire Laboratory combustion facility. These experiments are intended to extend the work of Evans and others (1976) by correcting the theoretical CO_2 emission factor for complete combustion to account for emission of other carbonaceous products. The CO_2 emission factor model is used with measured mass ratios to compute emission factors for other effluents and total fuel consumption. Comparisons are made between values based on the model and experimental measurements.

The observed mass ratios can be used to compute other mass ratios of interest such as THC:CO and TSP:CO. However, these ratios are not reported as such in this paper.

EMISSION MODELS

The combustion process includes preheating, flaming, and smoldering phases. Fire behavior and emissions data are not easily separated by combustion phase, and previous work on spreading fires has dealt mainly with overall emission factors, which represent weighted averages over all combustion phases. Only overall emission factors and emission models are discussed in this report. Quantities written with a circumflex (^) above them represent model values; quantities without a circumflex refer to measured values.

An Emission Factor Model for CO_2

The combustion products of forest fuels include CO_2, H_2O, CO, pure and oxygenated hydrocarbons, and particulate matter in forms and amounts dependent on fuel arrangement and composition, fuel moisture content, and burning characteristics. Because combustion is never complete, residue composed of carbonaceous and mineral material is left after the fire. Data from Knight and others (1975) and Hough and Albini (1978) suggest that for southern fuels about 2.5 percent of the original dry weight consists of mineral substances. The percentage of carbonaceous material remaining is dependent on the fuel and fire behavior, and is therefore more variable for any given fuel type. Although the percentage of carbon in the residue may be high in some cases, the amount of material remaining is usually sufficiently small (about 5 to 8 percent in slash pine needles) to make the amount of residual carbon insignificant when compared with the carbon leaving the fuel in the form of combustion products. For purposes of this paper, it is assumed that the carbon content of the residue is the same as that of the original dry fuel. With this simplification, an equation approximating the overall combustion of an ovendry fuel of composition $C_xH_yO_z$ can be written as

$$C_xH_yO_z + X_{O_2}O_2 \rightarrow X_{CO_2}CO_2 + X_{H_2O}H_2O + X_{CO}CO + X_{THC}C_qH_rO_sN_t + X_{TSP}C_uH_vO_w \quad (1)$$

where X refers to moles of the given component involved in burning 1 mol of fuel. In Equation (1), $C_qH_rO_sN_t$ denotes a mixture of hydrocarbons, including oxygenated and nitrogenated species. The mixture is referred to as total hydrocarbons. The solid- and liquid-phase hydrocarbons, designated as $C_uH_vO_w$, are referred to as particulate matter. The term $C_xH_yO_z$ represents consumed, rather than original, fuel because of the identical composition assumed for original and residual fuel. This assumption also means that a term to account for residue is not required in Equation (1). If a balance on carbon is written, then

$$x = X_{CO_2} + X_{CO} + qX_{THC} + uX_{TSP} \quad (2)$$

where, for example, qX_{THC} is the moles of carbon in X_{THC} moles of $C_qH_rO_sN_t$ produced in the consumption of 1 mol of fuel. An emission factor for CO_2 is, by definition,

$$\hat{EF}_{CO_2} = X_{CO_2}M_{CO_2}/M_F \quad (3)$$

where $\hat{EF}_{CO_2}$ (g/g) is based on Equation (1) and M_{CO_2} is the molecular weight of CO_2. The fuel molecular weight can be written as

$$M_F = (12x + y + 16z)\ \text{g/mol} \quad (4)$$

Substitution of Equations (2) and (4) into Equation (3) yields

$$\hat{EF}_{CO_2} = \frac{\left[\frac{xM_{CO_2}}{12x + y + 16z}\right]}{\left[1 + \frac{X_{CO}}{X_{CO_2}} + \frac{qX_{THC}}{X_{CO_2}} + \frac{uX_{TSP}}{X_{CO_2}}\right]} \quad (5)$$

A fuel composition corresponding closely to 50 percent C is given by x = 6, y = 9, z = 4 and is used here. This composition was used by Byram (1959) in combustion calculations and has since been verified in an approximate manner with analyses of southeastern fuels conducted by Knight and others (1975). Because M_{CO_2} = 44 g/mol, Equation (5) becomes

$$\hat{EF}_{CO_2} = \frac{1.82\ \text{g/g}}{\left[1 + \frac{X_{CO}}{X_{CO_2}} + \frac{qX_{THC}}{X_{CO_2}} + \frac{uX_{TSP}}{X_{CO_2}}\right]} \quad (6)$$

Effects of CO, THC, and TSP production on $\hat{EF}_{CO_2}$ can be evaluated through measurements of the ratios shown which,

it must be remembered, are molar (or mass) ratios of carbon.

For practical use, the C ratios of Equation (6) can be converted to ratios of mass concentrations (mg/m^3) through molecular weight ratios. The molecular weight of the hydrocarbon fraction is difficult to determine because both low- and high-molecular weight compounds are present in unknown quantities. For this study, propane (C_3H_8) with molecular weight of 44 g/mol is taken as a representative hydrocarbon. In addition, it is assumed that the particulate fraction is 95 percent C with a molecular weight of 12 g/mol. This figure may overestimate slightly the actual C percentage averaged over all combustion phases, but the error should not be large. Let R_i denote the ratio of effluent i mass concentration to CO_2 mass concentration, where i can represent CO, THC, or TSP. Then, through use of molecular weights, Equation (6) can be written as

$$E\hat{F}_{CO_2} = \frac{1{,}820 \text{ g/kg}}{[1 + 1.57R_{CO} + 3.0R_{THC} + 3.48R_{TSP}]} \quad (7)$$

If concentration data are in terms of parts per million (p/m),[3] the R_i represent ratios of molar concentrations and Equation (6) becomes

$$E\hat{F}_{CO_2} = \frac{1{,}820 \text{ g/kg}}{[1 + R_{CO} + 3.0\,R_{THC} + 0.95\,R_{TSP}]} \quad (8)$$

It is clear that when combustion is ideal, $R_{CO} = R_{THC} = R_{TSP} = 0$ in Equations (7) and (8) and $E\hat{F}_{CO_2} = 1{,}820$ g/kg. Dependent upon the units of experimental data, either Equation (7) or Equation (8) can be used for estimating emission factors and fuel consumption in forest fires. In the interest of simplicity, it is assumed for the remainder of this paper that concentrations are always expressed as mass concentrations. Thus Equation (7) is used in all subsequent calculations.

Model Applications

For field work, Equation (7) can be used in several ways, depending on how the effluent sampling is carried out. Most of the available information on surface-based particulate matter emissions for forest fires is based on sampling with filters in a method referred to as the flux method by Ward and others (see footnote 2). This method also can form the basis for sampling in the carbon balance technique. If the total flow of gaseous and particulate matter through a cross section of the entire plume is both measured and sampled for emissions during sample time, T, estimates can be made of the total fuel consumption and the fuel consumption rate during time T and of the corresponding emission factors. Several assumptions are inherent in the flux method. Probably the most critical one is that all effluents are present in a unit volume of sampled air in the proportion in which they were produced by the fire. Thus, the effects of plume processes such as fallout of particulate matter and conversion of sampled species to nonsampled species are regarded as negligible. Further, it is assumed that short-term variations in rate of effluent production and wind transporting the plume do not significantly affect the time-averaged concentrations and volumetric flow rate through a given plume cross section.

Consider a fire burning in a fuel type of interest with the combustion products transported downwind from the site. At some convenient downwind distance, let C_{CO_2}, A, and u represent the plume mass concentration of CO_2, cross-sectional area, and windspeed, respectively, averaged over sample time, T. If these quantities are representative of the entire plume, then the mass of fuel consumed during time T can be computed from

$$F\hat{C} = \frac{C_{CO_2} A u T}{E\hat{F}_{CO_2}} \quad (9)$$

where $E\hat{F}_{CO_2}$ is obtained from Equation (7). For most surface measurements it may not be possible to sample the entire plume because of limited manpower and instrumentation. Another complicating factor is variation in concentrations with height above the surface because effluents and ambient air are not uniformly mixed. Details on how the variables C_{CO_2}, A, and u can be used in the flux method under these complex sampling conditions are described by Ward and others (1974, 1980). If T is close to the total burning time, then $F\hat{C}$ should approximate the total consumption of fuel. An average fuel consumption rate for time T, $F\hat{C}R$, thus can be written as

$$F\hat{C}R = \frac{F\hat{C}}{T} = \frac{C_{CO_2} A u}{E\hat{F}_{CO_2}} \quad (10)$$

These same measurements may be used to estimate emission factors for CO, THC, and TSP. Because the R_i in Equation (7) are known, the emission factor for effluent i can be computed from

$$E\hat{F}_i = E\hat{F}_{CO_2} R_i \quad (11)$$

If information on emission factors only is desired, the flux method need not be used, although the measured R_i values should represent the entire plume cross section. The value of $E\hat{F}_i$ for effluent i can be estimated from combination of Equations (7) and (11).

A special case of the flux method and carbon balance technique uses Equation (7) in conjunction with sampling of effluents from smaller fires, such as those in laboratory experiments. This application of the flux method involves

[3] Although particulate matter concentrations are not measured in p/m, an equivalent concentration in p/m can be calculated from mass concentration data.

more controlled sampling than is possible with field burns, and was used in the experiments reported in this paper. In such studies, all effluents are usually funneled through an exhaust stack to the atmosphere and sampled continuously from ignition until the effluents are no longer produced at a significant rate anywhere in the fuel bed. Because of a highly variable burning rate with time, Equation (10) for rate of fuel consumption is best applied over short time intervals rather than over the total burning time.

METHODS

A series of experimental fires was conducted in the Southern Forest Fire Laboratory combustion facility to test the carbon balance technique as a means of estimating fuel consumption and emission factors for carbon dioxide, carbon monoxide, total hydrocarbons, and particulate matter. This section describes the experimental design, how the measurements were made, and possible sources of error.

Experimental Procedure

Experiments by a number of investigators have suggested that particulate matter emission factors are dependent on fire type and fire behavior variables (see Goss and Miller 1973, for example). Therefore, a requirement of this study was burning experimental fires throughout a range of fire intensities[4] to examine the emissions produced under different burning conditions. It was realized at the outset that even the highest intensity fires in these experiments would be located at the low end of the spectrum of real-world fire intensities. This limitation was due to the size of fire and rate of smoke production that could be accommodated within the 760-m^3 combustion room.

Eighteen fires consisting of nine headfires and nine backfires were burned in fuel beds made up of newly fallen slash pine needles. Use of only one fuel type reduced experimental variation in the data. The use of fuel moisture content, initial dry fuel loading, and fuel bed slope angle as independent variables provided a range of fire intensities. The study was conducted as two separate experiments. A block of nine headfires was burned first, followed by a block of nine backfires. Nominal levels of variation in the independent variables were as follows:

Moisture content	4, 11, 18 percent of dry fuel weight
Initial fuel loading	0.49, 1.46, 2.44 kg/m^2 (dry basis)
Fuel bed slope angle	0, 11.3, 22.5 degrees from horizontal

Basic designs for the two fire types are shown in figure 1. Within the block of headfires, fire CO2-1 was burned first and fire CO2-9 last. Backfires also were burned in ascending numerical order. It was assumed that experimental conditions did not vary with time. Such variation could cause errors in the results due to the order in which the fires were burned.

Prior to the experimental burns, several tests with pool fires were conducted to ensure that instrumentation was functioning properly. Carbon balances were run on two ethanol fires to check the carbon balance technique with a fuel of known composition. Mixing characteristics within the combustion room stack were also checked. Two xylene fires were then used to make similar tests with a soot-producing fuel.

Experimental Measurements

Fuel beds were constructed by uniformly distributing slash pine needles by hand into 1.22- by 0.92-m hardware cloth trays and then storing them in environmental cabinets for conditioning to the proper moisture content. Three beds were constructed for each of the three loading levels. These beds simulated in only a crude way the litter layers found in the field; gradients in moisture content and weathering found in real fuels were not present. In addition, the needles rested on a thin sheet of insulating material rather than on a moist layer of mineral soil.

An experiment began by placing the fuel bed on the burn table, which had been adjusted to the proper slope angle to simulate the effect of wind on the combustion process. Headfires were ignited at the bottom of the bed and were driven by the upslope component of buoyancy; backfires were ignited at the top of the bed and moved downslope against an upslope buoyancy force. All backfires reached a steady-state rate of spread, but this was not true for some headfires. Smoke from the fires was funneled through an exhaust stack directly above the bed. Samples of stack gas were withdrawn and prefiltered to remove particulate matter and moisture and then passed through stainless steel tubing to gas analyzers. Oxides of carbon were detected by MSA infrared analyzers; total hydrocarbons were detected with an MSA flame ionization detector. The total particulate matter samples were collected on 20- by 25-cm glass fiber filters in a high-volume sampler. Mass loss of the fuel bed was monitored with four load cells. An array of 0.16-cm diameter chromel-alumel thermocouples provided a vertical distribution of temperatures in the combustion zone and in the flame zone above the bed. Additional sensors were used to measure dynamic pressure and temperature of the stack gases for use in computing volumetric flow rates.

The fuel, fire, and emissions data were recorded in three ways. Some of the easily observed fuels and fire behavior data, as well as the particulate matter emissions and total fuel consumption, were recorded manually. Gas concentrations (in p/m) were recorded as functions of time on strip charts. These concentrations were later converted to total mass by the use of volume flow rates and sample times. In addition, gas concentrations, bed weight, stack

[4] Fire intensity is the rate of heat release per unit length of fire front in a spreading line fire.

Figure 1.–Experimental designs for headfires and backfires using fuel moisture, fuel loading, and fuel bed slope angle as independent variables.

HEADFIRES

	FUEL LOADING (kg/m^2)								
	0.49			1.46			2.44		
	SLOPE (degrees)			SLOPE (degrees)			SLOPE (degrees)		
MOISTURE (%)	0	25	50	0	25	50	0	25	50
4	CO2-7					CO2-5		CO2-1	
11		CO2-8		CO2-3					CO2-2
18			CO2-4		CO2-6		CO2-9		

BACKFIRES

	FUEL LOADING (kg/m^2)								
	0.49			1.46			2.44		
	SLOPE (degrees)			SLOPE (degrees)			SLOPE (degrees)		
MOISTURE (%)	0	25	50	0	25	50	0	25	50
4	CO2-16				CO2-17				CO2-12
11		CO2-15				CO2-11	CO2-13		
18			CO2-18	CO2-10				CO2-14	

emperatures, and pressures were sensed at 1-s intervals by a real-time data acquisition system. After each fire, the data were transferred to magnetic tape for storage and subsequent analysis.

Data Analysis

Data collected were categorized in terms of emissions production, fuel layer, and fire behavior variables. Unfortunately, magnetic tapes for two of the fires were accidentally destroyed. Therefore, gaseous emissions data were taken from the strip-chart records.

Balances between carbon in the consumed fuel and carbon measured as gases and particulate matter were made. Both the original and residual fuel (and hence fuel consumed) were assumed to contain 50 percent carbon. Carbon content of the particulate matter produced was assumed to be 95 percent; propane (C_3H_8) was assumed to represent an average chemical formulation of the many hydrocarbon gases produced.

Because only 2 of the 18 experimental fires were duplicates, additional tests were conducted to check the reproducibility of the results. Five headfires in slash pine needles were burned under nearly identical conditions. Dry fuel weights were 1,231 g, fuel moisture contents were 18 percent, and slope angles of the fuel layer from horizontal were 11.3 degrees. The mean total production of CO_2 per fire was 469 g with a standard error of 19 g. In addition, the mean particulate matter emission factor (based on gravimetric measurements) was 17.6 g/kg with a standard error of 1.1 g/kg. The maximum difference between carbon lost from the bed and carbon measured in the stack was 10.3 percent. These results indicate that repeated fires are reproducible and that much of the variation in the 18 experimental fires can be attributed to varying fuel and burning conditions.

RESULTS

Experimental Data Summary

Data for the 18 experimental fires are shown in table 1 with values of fuel consumption and total mass of CO_2, CO, THC, and TSP measured for the fires. In addition, R_i values (mass of effluent i divided by mass of CO_2) are given which can be used in equation (7) for computing a model emission factor for CO_2. The R_i data can also be used to compute other effluent mass ratios of interest. For

Table 1.–Effluent production, effluent mass ratios, fuel consumption, and carbon balance[a] for headfires and backfires in slash pine needles burned in the laboratory

Fire No.	Mass of effluent (g)				Fuel consumption (kg)	Percent difference carbon balance	$R_i = \frac{\text{Grams of i}}{\text{Grams of } CO_2}$, i = CO, THC,TSP		
	CO_2	CO	THC	TSP			R_{CO}	R_{THC}	R_{TSP}
				HEADFIRES					
CO2-1	3,828	355	40	73	2.526	2.7	0.0927	0.0104	0.0191
-2	4,470	320	20	60	2.597	9.5	.0716	.0045	.0134
-3	2,732	142	6	14	1.547	6.3	.0520	.0022	.0051
-4	752	28	2	3	.480	-8.2	.0372	.0027	.0040
-5	2,296	208	13	36	1.456	4.3	.0906	.0057	.0157
-6	2,244	152	7	32	1.382	3.1	.0677	.0031	.0143
-7	942	30	5	3	.514	7.2	.0318	.0053	.0032
-8	986	28	5	3	.525	9.1	.0284	.0051	.0030
-9	4,994	180	13	12	2.660	9.4	.0360	.0026	.0024
				BACKFIRES					
CO2-10	2,523	131	13	17	1.567	-0.6	.0519	.0052	.0067
-11	2,996	128	5	5	1.623	8.2	.0427	.0017	.0017
-12	4,558	229	17	6	2.655	2.5	.0502	.0037	.0013
-13	3,869	315	29	24	2.546	-2.9	.0814	.0075	.0062
-14	4.932	233	21	13	2.642	10.9	.0472	.0043	.0026
-15	895	58	7	3	.481	14.3	.0648	.0078	.0034
-16	931	33	2	2	.473	13.8	.0354	.0021	.0021
-17	2,813	131	10	5	1.578	5.6	.0466	.0036	.0018
-18	711	49	10	2	.459	-2.2	.0689	.0141	.0028

[a]The fuel is assumed to be 50 percent carbon for purposes of the carbon balance.

example, the ratio TSP:CO for the fire CO2-1 is 0.0191: 0.0927, or 0.206. Also shown in table 1 is the carbon balance percent difference which is based on the difference between carbon in the form of gases and particulate matter which is measured experimentally, and carbon which has disappeared from the fuel bed in the form of a weight loss.

Emission Factors and Fuel Consumption

Table 2 lists measured and computed values of emission factor for CO_2, CO, THC, and TSP. The model CO_2 emission factor comes from Equation (7) and all others come from Equation (11). Values of R_i for use in Equation (7) are listed in table 1. Also in table 2 are percent differences between measured and model values. These figures closely follow the carbon balance differences, as would be expected.

Table 3 compares total fuel consumption from Equation (9) with measured values. Total production of CO_2 in the numerator of Equation (9) is from table 1, whereas $\hat{EF}_{CO_2}$ in the denominator is from table 2. As for the emission factor data, percent differences between the calculated and measured values follow the accuracy of the carbon balance in table 1.

The carbon balance data show that measured carbon usually exceeds the assumed loss of carbon from the fuel bed, and that the maximum percent difference is about 15 percent. Tables 1, 2, and 3 also show that percent differences associated with quantities calculated from Equation (7) follow very closely those of the carbon balance. In table 2, almost the same differences are associated with each of the four effluents for a given fire. These results suggest that errors in measurement of CO_2 concentrations (and hence in $\hat{EF}_{CO_2}$) caused similar errors in quantities computed for other effluents by Equations (9) and (11). One source of error is lack of sensitivity in the CO_2 gas analyzer, which probably prevented accurate measurement of CO_2 background concentrations. This instrument was used, nevertheless, because others available could not measure the large concentrations of CO_2 produced occasionally during the fires. Another possible source of error is uncertainty in the carbon fraction of the original fuel. As will be shown later, only a small change from the assumed value of 50 percent would be necessary to bring measured values and those computed by Equations (7), (9), and (11) into excellent agreement.

Table 2.–Percent difference (P.D.) between measured emission factors (g/kg) and values computed from Equation (7) or Equation (11)

Fire No.	CO_2			CO			THC			TSP		
	Meas.	Eq. (7)	P.D.	Meas.	Eq. (11)	P.D.	Meas.	Eq. (11)	P.D.	Meas.	Eq. (11)	P.D.
						HEADFIRES						
CO2-1	1,515	1,464	3.4	141	136	3.6	15.8	15.2	3.9	28.9	28.0	3.2
-2	1,721	1,552	10.3	123	111	10.3	7.7	7.0	9.5	23.1	20.8	10.5
-3	1,766	1,646	7.0	92	86	6.7	3.9	3.6	8.0	9.0	8.4	6.9
-4	1,567	1,685	-7.3	58	63	-8.3	4.2	4.5	-6.9	6.3	6.7	-6.2
-5	1,577	1,499	5.1	143	136	5.0	8.9	8.5	4.6	24.7	23.5	5.0
-6	1,624	1,562	3.9	110	106	3.7	5.1	4.8	6.1	23.2	22.3	4.0
-7	1,833	1,690	8.1	58	54	7.1	9.7	9.0	7.5	5.8	5.4	7.1
-8	1,878	1,700	9.9	53	48	9.9	9.5	8.7	8.8	5.7	5.1	11.1
-9	1,877	1,697	10.1	68	61	10.9	4.9	4.4	10.8	4.5	4.1	9.3
						BACKFIRES						
CO2-10	1,610	1,624	-0.9	84	84	0.0	8.3	8.4	-1.2	10.8	10.9	-0.9
-11	1,846	1,688	8.9	79	72	9.3	3.1	2.9	6.7	3.1	2.9	6.7
-12	1,717	1,663	3.2	86	83	3.6	6.4	6.2	3.2	2.3	2.2	4.4
-13	1,520	1,553	-2.1	124	126	-1.6	11.4	11.6	-1.7	9.4	9.6	-2.1
-14	1,867	1,661	11.7	88	78	12.0	7.9	7.1	10.7	4.9	4.3	13.0
-15	1,861	1,601	15.0	121	104	15.1	14.6	12.5	15.5	6.2	5.4	13.8
-16	1,968	1,702	14.5	70	60	15.4	4.2	3.6	15.4	4.2	3.6	15.4
-17	1,783	1,669	6.6	83	78	6.2	6.3	6.0	4.9	3.2	3.0	6.5
-18	1,549	1,569	-1.3	107	108	-0.9	21.8	22.1	-1.4	4.4	4.4	0.0

Table 3.–Percent difference between measured fuel consumption and values computed from Equation (9)

Fire No.	Measured fuel consumption (kg)	Fuel consumption from Eq. (9) (kg)	Percent difference
	HEADFIRES		
CO2-1	2.526	2.615	3.5
-2	2.597	2.880	10.3
-3	1.547	1.660	7.0
-4	.480	.446	-7.3
-5	1.456	1.532	5.1
-6	1.382	1.437	3.9
-7	.514	.557	8.0
-8	.525	.581	10.1
-9	2.660	2.943	10.1
	BACKFIRES		
CO2-10	1.567	1.554	-0.8
-11	1.623	1.775	8.9
-12	2.655	2.741	3.2
-13	2.546	2.491	-2.2
-14	2.642	2.969	11.7
-15	.481	.559	15.0
-16	.473	.547	14.5
-17	1.578	1.685	6.6
-18	.459	.453	-1.3

Of interest is whether the TSP emission factor can be regarded as constant under different burning conditions. Although available data (Ward and others 1974, 1980) indicate that EF_{TSP} is a function of fireline intensity and fire type, the question is not yet fully resolved. The data of table 2 do not support the idea of a constant emission factor. Values of EF_{TSP} range from about 2 to 30 g/kg.

DISCUSSION

Feasibility of the Carbon Balance Technique

It is clear that the question of feasibility of the carbon balance technique for field applications cannot be answered in a final way with a single laboratory study. However, the results in tables 2 and 3 suggest that computational accuracy follows closely the accuracy of the carbon balance. Though the measured carbon exceeds carbon assumed lost from the fuel bed for all but four fires, this study tends to confirm the initial assumption that, for practical purposes, only CO_2, CO, THC, and TSP need be included as components in the carbon balance.

The present results indicate that if errors in effluent concentration and air volume measurement can be limited to 15 or 20 percent in field experiments, the carbon balance method should be acceptably accurate for most applications. However, a number of errors can be associated with the technique that should be pointed out. Among them are uncertainties in carbon percentages and molecular weights of original and residual fuel, and in hydrocarbons and particulate matter produced. Errors result from incomplete mixing and the nearly impossible task of sampling the entire plume. These errors are reduced considerably in laboratory experiments such as those reported in this study. Finally, errors caused by wall losses in instrument tubing, condensation, and desorption from filters must be contended with. Despite these and other possible errors, the results of the present study suggest that the carbon balance technique can be useful in both laboratory and field experiments.

Because of some of these uncertainties, definite statements about the accuracy of Equations (7), (9), and (11) cannot be made, though there is little doubt of their general validity. These equations produce smaller emission factor and larger fuel consumption values than those measured. The differences are consistent with two explanations: (a) error in the constant 1,820 g/kg of Equation (7) due to underestimation of the fuel carbon fraction, or (b) errors in CO_2 concentrations which affected subsequent computations. Other errors, such as those listed above, are believed to have produced only negligible effects in comparison with either (a) or (b). If (a) were true, a value of about 1,940 g/kg would bring the model values into agreement with the measurements. This implies a carbon fraction of about 53 percent in the original fuel. Though no data on needles of this experiment are available, elemental studies on six samples of slash pine needles by Knight and others (1975) produced a carbon percentage of 52.7 percent. On the other hand, zero readings on the CO_2 gas analyzer were undoubtedly in error due to lack of sensitivity at small concentrations. If the error was a systematic one (rather than random), CO_2 background concentrations may have been consistently underestimated, causing a slight overestimation of CO_2 for most of the fires. The extent to which errors (a) and (b) were present during the burns is unknown.

Practical Application

Successful application of the carbon balance technique as a measurement tool partially depends on the validity of the constant 1,820 g/kg in Equation (7). The remainder of the input to Equations (7), (9), and (11) comes from measurement of mass concentrations and air volume. The flux method discussed earlier seems well suited for either aerial or surface measurements made in field experiments. However, because the method has not been used extensively, little can be said of its possible limitations. In surface applications, the demands on personnel and equipment needed for adequate sampling may be a drawback. Studies of the extent of sampling required for meaningful results are needed. In aerial sampling with aircraft, a possible limitation (especially on small fires) is that effluent con-

ntrations throughout most of the plume may not be uch greater than background values. This problem was ted by Ward and others (see footnote 2).

A question of practical interest discussed earlier is hether carbonaceous products other than CO_2 can be nored for purposes of estimating emission factors and fuel nsumption in operational burns or smaller burns used for search purposes. The data in tables 1, 2, and 3 can be ed to show that if all the R_i in Equation (7) are regarded zero, computed emission factors for CO, THC, and TSP d corresponding fuel consumptions are within 20 percent the measured values. If the measured R_{CO} is included in e calculations, the differences are within 15 percent. herefore, these experiments indicate that accuracy is only ghtly improved by accounting for emissions other than O_2 in the analysis. The value of this result is that a TSP ission factor can be obtained from mass concentration easurements of CO_2 and TSP only, rather than requiring ditional concentrations of CO and THC.

Experiments with the carbon balance technique under ld conditions are needed. If proven feasible in these situ- ons, the technique should be an aid to persons responsi- e for management of air quality as well as those engaged fire and smoke management research. The method will ovide estimates of emission factors for carbonaceous mbustion products and of fuel consumed while requiring ly measurements of effluent concentration and air lume.

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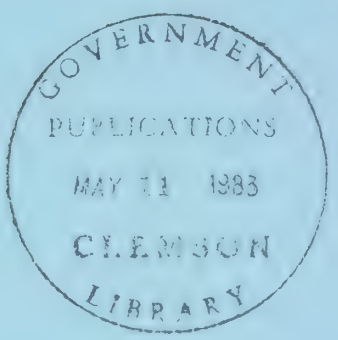

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Infestation Pattern and Survival of Bark Beetles in Loblolly Pines Treated with Paraquat

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Abstract.--Loblolly pines were treated with 2 or 5 percent paraquat by the bark streak method in June, August, or November, and effects of season of treatment and paraquat concentration on attacks by engraver beetles and black turpentine beetles were observed for 6 months. Four weeks after spring and summer treatments, beetles of both species began to infest loblolly pines. Black turpentine beetles began to infest trees treated in the fall about 4 months later. Of the 240 trees treated in each season, 104 became infested after spring treatment, 85 after summer treatment, and 39 after fall treatment. Despite the large number of infested trees, only a few died during the 6-month test and these were in the intermediate and suppressed crown classes. Presence of secondary species and borers in the treated trees was noted.

Keywords: Ips calligraphus, Dendroctonus terebrans, Coleoptera:Scolytidae, lightwood induction, tree mortality.

When southern pines are wounded and treated with paraquat to induce formation of resin-soaked wood called lightwood, pine bark beetles of various species are attracted to the treated trees. The most troublesome insect species on the Piedmont Plateau and Southeastern Coastal Plain are the engraver beetle (EB) (Ips calligraphus (Germar)) and the black turpentine beetle (BTB) (Dendroctonus terebrans (Olivier)) (Moore 1978; Goldman and Parker 1978). Treated trees can be protected by spraying their lower boles with a persistent insecticide, but the returns from paraquat treatment may not be sufficient to justify the cost of insecticide spraying. A major goal of the Lightwood Research Coordinating Council, therefore, is to develop paraquat treatments that do not create a need for insect protection. In the study described here, effects of paraquat concentration and season of treatment on insect attack were observed in a stand near Chapel Hill, North Carolina, on land owned by North Carolina State University. The succession of insects attacking after paraquat treatment, brood production, and emergence were monitored for 6 months after treatment.

Earlier studies have shown that insect-caused mortality can be decreased by reducing wound size and paraquat concentration (Drew 1977; Hertel and Williams 1975; Moore 1978). Season of treatment has also been shown to influence tree mortality (Drew 1977; Moore 1978). Finally, I have observed

that, although more than 90 percent of the BTB and 22 percent of the EB emerged from paraquat-treated trees colonized by bark beetles, negligible numbers of untreated trees were attacked by the emerging brood (Moore 1978; Moore and others 1979).

MATERIALS AND METHODS

Trees selected for treatment were loblolly pines (Pinus taeda L.) in a 33-year-old plantation. At that time, tree d.b.h. averaged 25 cm and site index was estimated to be 24 m (50-year basis). Only trees that were free of insect infestations and had a d.b.h. of at least 10 cm were treated. Each plot consisted of a row of 20 treated loblolly pines. Trees were treated in three seasons--spring (June), summer (August), and fall (November). Paraquat was applied by the bark streak method, in which a streak of bark about 2 cm wide is removed from one-third of the circumference of the tree approximately 20 cm above the ground. The wound was made with a modified chainsaw chipper, and paraquat was applied to designated trees at the rate of 5 ml per tree with a calibrated applicator.

Four treatments were included: wound receiving 2 percent paraquat, wound receiving 5 percent paraquat, wound only, and untreated control. Treatments were applied in a randomized block design with three blocks containing 240 trees each.

For 6 months after treatment, trees were examined weekly until November but only monthly thereafter, because cold weather severely reduced beetle activity. At each examination, newly infested trees (with one or more pitch tubes) were counted. Two bark samples (10 by 10 cm) were collected between the ground line and 2.5 m on each of two infested trees, if available, per replication. Attacks, live and dead adults, eggs, brood, and emerged adults were counted in each sample.

I attempted to cut out entire BTB gallery systems for the count of the BTB, but finally used regular 10- by 10-cm samples. If the samples were taken slightly below the tunnel entrance, at least the first cluster of eggs, larvae, and other brood were normally found, frequently with the parent adults.

Data were subjected to analysis of variance. Individual F tests were performed for each of the following variables: number of trees attacked by EB, number of trees attacked by BTB, number of EB alive and emerging from trees, and number of BTB alive and emerging from trees. Recognized sources of variation were seasons, treatments, season x treatment, and replications (blocks).

RESULTS AND DISCUSSION

Patterns of Infestation

Both BTB and EB infested trees during the 4th week after summer applications of paraquat. Only the BTB infested trees treated in the fall, and its infestations did not appear until 4 months after treatment. All but 2 of the 240 test trees were free of bark beetle infestation at the end of the 4th month after fall treatment. Only 137 of the 240 trees in the spring test and 155 trees in the summer test were not infested by EB, BTB, or both after the 4th month.

The ambrosia beetle (Platypus flavicornis (F.)) and Pityophthorus bellus Blackman attacked only scattered trees after initiation of infestation by EB. Platypus flavicornis was found in treated trees 5 weeks after paraquat treatment in the spring and summer tests, but did not occur in the fall test by the end of 6 months. Pityophthorus bellus was found in treated trees at the 14th week after treatment in the spring test and at the 7th week in the summer test. Monochamus sp. was found 2 months after treatment in the spring and summer tests, primarily in trees that were severely infested with bark beetles or had died.

In most instances, BTB attacked below 1 m height on the bole. It did not concentrate attacks on the treated face but next to it, or at the base of the treated trees. In comparison, EB usually attacked on the bole above the

treated face. In weaker trees (intermediate or suppressed), EB attacks continued away from the treated face.

Seasonal Differences

Number of infested trees.--The primary observed difference between seasons (table 1) was the lower number of trees infested after the fall treatment, which was primarily due to the low level of insect activity during the winter. Differences between seasons were significant at the 0.05 level only for the number of trees infested by EB ($F = 3.71$). The range of differences by season in numbers of attacked trees is similar to that obtained by Moore (1978) at the Savannah River Plant in South Carolina. The interaction between season and treatment was significant at the 0.05 level ($F = 3.47$) for BTB. The ratios of trees successfully infested (with brood following) to trees superficially infested by EB and BTB were about the same for all seasons and treatments (table 1, columns 5 and 6) except for the 2 and 5 percent paraquat treatments in the fall test.

Tree mortality.--Eleven of the 103 infested trees died during the 6 months after the spring test. Most of the trees that died were in the intermediate and suppressed crown classes, and most were attacked by EB. Concentration of paraquat did not influence rate of mortality. In the summer test, only 2 out of 85 infested trees died. None of the 37 infested trees in the fall test died during the next 6 months. Some BTB emerging from summer-test trees the following spring contributed to the infestation of trees treated in the fall.

Numbers of brood and emerged beetles.--During the spring test, EB brood emerged primarily from the 11th to the 8th week after treatment, with the main portion emerging during the 12th week. BTB brood began to emerge 17 weeks following treatment in the spring test and continued until the end of the test. It is important to note that during the 18th week after treatment BTB were still attacking and laying eggs in live trees that had been initially attacked as early as the 4th week after spring treatment. During the summer test, EB brood began to emerge 9 weeks after treatment, but the main group emerged during the 11th and 12th weeks. Most of the BTB overwintered in the trees as larvae or pupae and emerged to attack trees from the fall test the following March.

Analysis of variance which compared survival in the three seasonal tests showed that there were significantly higher numbers and percents of live and emerged BTB in the fall test than during the other two seasons (table 2). No trees were infested by EB during the 6 months after the fall treatment. Duncan's tests showed that significantly fewer EB brood were produced after the summer treatment than after the spring treatment.

Comparisons Among Treatments

Number of infested trees.--Untreated controls and wounded trees receiving no paraquat had only slight, mostly superficial infestations of BTB and EB, while the paraquat-treated trees were moderately to heavily infested. A Duncan's multiple range test showed that there were differences at the 0.01 level for both species of bark beetles between the control and wound-only treatments and the two treatments receiving paraquat. There were no significant differences between the 2 and 5 percent paraquat treatments--an indication that, in terms of bark beetle infestation, either concentration may be used with the bark streak method of application. If other factors such as production of lightwood are the same, however, the lower concentration of paraquat should be used. There was no difference in infestation between untreated controls and wound-only controls. By comparison, at the Savannah River Plant, wounded trees receiving no paraquat were heavily infested by the BTB (Moore 1977). The results in the range of differences are

Table 1.--Mean number of trees infested with Ips calligraphus and Dendroctonus terebrans and those producing brood

Treatment	Trees with Ips only	Emergence	Trees with Dendroctonus only	Emergence	Trees infested by both spp., including ones not producing brood	Trees infested by both spp. producing brood	
						Number	Percent
			SPRING				
Wound and 2% paraquat	4.0	yes	2.3	yes	15.3	10.7	70
Wound and 5% paraquat	5.3	yes	2.6	yes	13.6	10.7	79
Wound only	.6	yes	3.0	yes	5.3	3.3	62
Untreated control	.3	yes	.0	no	.6	.0	0
			SUMMER				
Wound and 2% paraquat	2.6	yes	3.3	yes	11.0	7.0	64
Wound and 5% paraquat	2.6	yes	4.3	yes	15.0	9.0	60
Wound only	.3	yes	2.0	no	2.6	1.0	38
Untreated control	.0	0	.0	0	.0	.0	0
			FALL				
Wound and 2% paraquat	.0	0	7.6	yes	7.6	2.7	35
Wound and 5% paraquat	.0	0	9.6	yes	9.6	2.7	28
Wound only	.0	0	.3	no	.3	.0	0
Untreated control	.0	0	.0	0	.0	.0	0

Each figure is the average of three replications, 20 trees per replication, at the end of 6 months (represented by two 10- by 10-cm samples per tree).

Table 2.--Mean number and percent of *Ips calligraphus* and *Dendroctonus terebrans* brood in paraquat-treated trees

Treatment	*Ips calligraphus*		*Dendroctonus terebrans*		Trees infested by both spp. producing brood
	No. live galleries and emerged	Percent of live and emerged brood	No. live in galleries and emerged	Percent of live and emerged brood	
			SPRING		
Wound and 2% paraquat	5.6	29.3	19.5	91.0	10.7
Wound and 5% paraquat	11.5	56.2	19.9	59.1	10.7
Wound only	9.7	51.3	6.1	64.8	3.3
Untreated control	.0	.0	.0	.0	.0
			SUMMER		
Wound and 2% paraquat	9.7	31.2	9.7	76.8	7.0
Wound and 5% paraquat	3.8	18.3	16.4	89.1	9.0
Wound only	2.3	33.3	.0	.0	1.0
Untreated control	.0	.0	.0	.0	.0
			FALL		
Wound and 2% paraquat	.0	.0	26.6	100.0	2.7
Wound and 5% paraquat	.0	.0	29.5	100.0	2.7
Wound only	.0	.0	.0	.0	.0
Untreated control	.0	.0	.0	.0	.0

Each figure is the average of three replications, 20 trees per replication, at the end of 6 months (represented by two 10- by 10-cm samples per tree).

generally similar to those for the unsprayed trees in an earlier study (Moore and others 1979).

Numbers of brood and emerged beetles.--Brood production and survival were consistently higher for BTB than for EB (table 2). The development and survival of EB were generally higher on the backs of trees than on the boles above the treated faces, which became dry and filled with resin for up to 4 m from the base. Presumably, lightwood formation affected Ips on the treated surface because Anderson and Anderson (1968) state that the low water content of inner bark alone has no direct effect on attack or development of Ips except in cases of extreme water loss. Numbers of brood and emerged beetles were significantly higher in treatments receiving paraquat (at the 0.05 level, $F = 4.07$) only for BTB. Duncan's tests showed for EB that the wound-only treatment had significantly higher brood (0.05 level) than the untreated control; the two paraquat treatments were also higher than the untreated control. For the BTB, wound-only and the two paraquat treatments were significantly higher (0.01 level) than the untreated control. There was no difference between the 2 and 5 percent paraquat treatments for either species of bark beetle.

Although many paraquat-treated trees became infested by bark beetles after the 4th week following treatment, few were subsequently killed. Trees which were killed usually contained BTB and EB plus P. flavicornis and Monochamus sp. Differences in number of trees infested and number of brood produced were due to limited beetle activity in the fall, as compared to the other two seasons. The paraquat treatments caused significantly more bark beetle infestations, and the infested trees produced higher numbers of brood than did the untreated trees. Nevertheless, the tree mortality was not severe enough, even in the 5 percent paraquat treatment, to require insecticidal protection from bark beetles.

Mortality was checked weekly for 6 months, but in a subsequent examination 1 year after the final treatment, no additional mortality was noted. Also, the conclusions are applicable only to paraquat concentrations of 5 percent or less applied to bark streaks. Injection has caused greater mortality than bark streak application in some studies. It appears, however, that insecticide application may not be necessary under the conditions noted when loblolly pines are treated for lightwood induction in the Carolinas.

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Loblolly pines were treated with 2 or 5 percent paraquat by the bark streak method in June, August, or November, and effects of season of treatment and paraquat concentration on attacks by engraver beetles and black turpentine beetles were observed for 6 months. Four weeks after spring and summer treatments, beetles of both species began to infest loblolly pines. Black turpentine beetles began to infest trees treated in the fall about 4 months later. Of the 240 trees treated in each season, 104 became infested after spring treatment, 85 after summer treatment, and 39 after fall treatment. Despite the large number of infested trees, only a few died during the 6-month test and these were in the intermediate and suppressed crown classes. Presence of secondary species and borers in the treated trees was noted.

KEYWORDS: Ips calligraphus, Dendroctonus terebrans, Coleoptera:Scolytidae, lightwood induction, tree mortality.

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CHANGES IN SOIL FERTILITY FOLLOWING PRESCRIBED BURNING ON COASTAL PLAIN PINE SITES

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Changes in Soil Fertility Following Prescribed Burning on Coastal Plain Pine Sites

by

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Abstract.--Soil and forest floor samples were collected from four prescribed burning studies in the Atlantic and Gulf Coastal Plains. The surface textures of soils ranged from sands to silt loams and the drainage classes from well to poorly drained. Burning treatments had been in force from 8 to 65 years. Reduction of the forest floor and its chemical constituents was related to frequency of burning; however, a protective organic horizon remained on all soils. Burning was found to have had no deleterious effect on organic matter or nitrogen in surface mineral soil. A comparison of earlier results with present findings suggests that annual winter burning may increase nitrogen in surface mineral soil while annual summer burning appears to reduce the total nitrogen content. Prescribed burning consistently increased the amount of available phosphorus. Fractionation of soil phosphorus indicated that burning resulted in the deposition of no specific form of phosphorus but accelerated the mineralization and cycling of the nutrient. Without burning, 50 to 60 percent more calcium accumulated in the forest floor and a correspondingly lower amount in the surface 10 to 16 cm of mineral soil. It is postulated that without burning, immobilization of calcium in the forest floor can lead to nutrient imbalance and accelerated soil weathering over a long period.

Keywords: Forest soils, forest floor mineral cycling, soil development, Pinus palustris, P. elliottii, P. taeda, phosphorus fractions.

Prescribed burning is recognized as one of the most effective and economical tools for silvicultural management of southern pine. Burning maintains pine as a monoculture in the ecological succession and suppresses the hardwood understory (Cooper 1971; Langdon 1971). Because fire destroys organic matter and is known to volatize appreciable quantities of nitrogen, nutrient loss and possible effects on site quality have been a concern in the use of prescribed fire.

Studies on nitrogen volatilization indicate that 30 to 112 kg/ha of nitrogen may be lost with prescribed burning of southern pine stands, depending on the nitrogen content of the litter, amount of litter burned by the fire, and burning intensity (Curtis and others 1977; Wells 1971). Analysis of soils under pine stands suggests that burning increases nitrogen fixation. After a portion of the litter is removed from these sites by fire, frequently the herbaceous vegetation contains a large portion of native leguminous plants (Lewis and Harshbarger 1976) which increases soil nitrogen. Jorgensen and Wells (1971) reported that prescribed burning increases nitrogen fixation by soil

microorganisms on wet sites. Studies of Coastal Plain soils indicate that total nitrogen content is not drastically reduced by burning but that its availability may be decreased (Wells 1971). Long-term results of burning on different Coastal Plain soils have not been determined (Wells and others 1979).

Phosphorus is frequently deficient on many Coastal Plain pine sites (Pritchett 1979). As indicated by Wells and others (1979), how prescribed burning affects phosphorus chemistry of forest soils is not known, although it is known that burning tends to increase "available phosphorus" in surface soil. The change in mineral soil pH and soluble cations after burning may produce a long-term effect on phosphorus solubility.

The release of cations in forest litter after burning has been well documented (Heyward and Barnette 1934; Metz and others 1961; Wells 1971), and an increase in pH noted. Neither the duration of this pH change after prescribed burning nor the effects of cation release for differently textured soils are well documented. Examples of where calcium, potassium, or magnesium additions to southern pine on undisturbed Ultisols resulted in increased growth could not be found in the literature. Pritchett (1979) indicated that these elements are seldom deficient in forest sites.

Besides the obvious effect of fire on mineral release, a long-term effect on soil weathering and development may result from prescribed burning. Herbauts (1980) reports evidence that, in slightly podzolized soils, amorphous oxides and cations from the surface mineral soil are leached by organic acids from the forest floor. Burning markedly reduces the level of organic matter in the forest floor (Curtis and others 1977). The remaining organic matter in the form of "charcoal" or partly charred material is less water soluble than the original litter and, thus, may serve as cation exchange material in surface mineral soil (Wells and Davey 1966).

The objectives of this study were (1) to determine the effect of prescribed burning on the nutrient content in the forest floor after 8 to 65 years, and (2) to determine changes in chemical forms of phosphorus and concentrations of other nutrients in the surface mineral soil on a range of Coastal Plain pine sites.

MATERIALS AND METHODS

Established prescribed burning studies which comprise a range of soil textures, drainage classes, topographic positions, and understory vegetation were selected in the Coastal Plain for study. None of the studies sampled had a detailed soil analysis before the burn treatments; however, interim burning effects were reported for two of the studies (Heyward and Barnette 1934; Metz and others 1961; Wells 1971). Brief descriptions of the four areas sampled follow.

Study Areas

Alabama.--This study is located on the Escambia Experimental Forest near Brewton, Alabama, on upper Coastal Plain terrain. Soils on the study area are classed as Benndale (Typic Paleudult, coarse loamy siliceous thermic), complexed with Orangeburg (Typic Paleudult, fine loamy siliceous thermic), Troup (Grossarenic Paleudult, loamy siliceous thermic), and Saffell (Typic Hapludult, loamy skeletal siliceous thermic). Overstory vegetation consists of 60- to 70-year-old longleaf pine (Pinus palustris). The stand had been thinned to prescribed basal areas at the beginning of the study. Site index (age 50) ranged from 19 to 24 m on these soils. Understory vegetation consists of grasses, forbs, and small woody sprouts. Large hardwoods were removed initially. Numerous small, hardwood sprouts had reestablished themselves on the control plot.

Plots were 0.16 ha with eight replicated blocks. Treatments sampled

were no-burn control and a biennial winter burn. The study was initiated in 1970, and the burn plots had been subjected to five fires. The last winter burn was applied approximately 4 months before sampling.

Florida.--This study is located on the Osceola National Forest in north-central Florida flatwoods on level Coastal Plain terrain. Soil on the study area is classed as Leon, sand (Aeric Haplaquod, sandy siliceous thermic) with an organic pan between 46 and 61 cm deep. The overstory vegetation contains mixed, naturally seeded longleaf and slash (P. elliottii) pines 60 to 70 years old. Site index (age 50) for the study area is 20 m, and average basal area is approximately 15.3 m^2/ha. Understory vegetation consists largely of saw-palmetto (Serenoa repens), gallberry (Ilex glabra), runner oak (Quercus pumila), blueberry (Vaccinium spp.), lyonia (Lyonia lucida), wiregrass (Aristida spp.), and broomsedge (Andropogon spp.). Cattle are grazed on the study area and may have altered understory vegetation.

Plots are 0.81 ha with six replications in a randomized block design. Treatments consist of no-burn control, periodic winter burn (every 4 years), and annual winter burn. The annual winter burn was not imposed until 6 years after initiation of the study; at the time of sampling, there had been 14 burns.

Louisiana.--This study is located in north-central Louisiana on a middle Coastal Plain site near the town of Urania on land owned by Louisiana Pacific Corporation. This study, 65 years old at time of sampling, has been frequently referred to in the literature as the "Roberts Plots." Soil is classed as Frizzel (Glossaquic Haplundalf, coarse-silty siliceous thermic). Previous reports on the study have referred to the soil series as a Montrose silt loam (Murad and others 1979). A detailed description of vegetation on the plots is also given by Murad and others (1979). Overstory vegetation consists of a 65-year-old longleaf pine stand established from a natural seedfall. Understory vegetation consists of bluestem grass (Andropodon spp.) on the burn plot and hardwood trees of 10 to 15 cm d.b.h. on the unburned control plot. Basal area for the stand is estimated to be about 18 to 20 m^2/ha.

Plots are approximately 0.10 ha. Treatments consist of a no-burn control and an annual winter burn with no replication. Eleven months before sampling, a wildfire burned the control plot at a fairly high intensity and may have had a pronounced effect on some chemical properties measured. This was the only wildfire to burn the control plot in the 65-year study. Throughout the study, burning treatments have been intense headfires, while burns imposed on the other three study areas generally have been backfires or flank fires.

South Carolina.--This study is located in eastern South Carolina on a Pleistocene terrace of the lower Coastal Plain. The terrain is nearly level and is poorly to somewhat poorly drained. Soils are described as Bayboro (Umbric Paleaquult, clayey mixed thermic), Bladen (Typic Albaquult, clayey mixed thermic), Coxville (Typic Paleaquult, clayey kaolinitic thermic), Dunbar (Aeric Paleaquult, clayey kaolinitic thermic), Duplen (Aquic Paleudult, clayey kaolinitic thermic), Goldsboro (Aquic Paleudult, fine-loamy siliceous thermic), and Lynchburg (Aeric Paleaquult, fine-loamy siliceous thermic). The overstory is 70-year-old loblolly pine (P. taeda) with a site index (age 50) of 27 to 30 m. Understory vegetation varies drastically with the burn treatment and has been documented by Lewis and Harshbarger (1976). Burning treatments were begun 30 years prior to the current sampling.

Plots are 0.10 ha, with three replications located on the Santee Experimental Forest near Charleston and two replications located on Westvaco Corporation land near Andrews, South Carolina. Treatments consist of no-burn control, periodic winter burn, periodic summer burn, annual winter burn, and annual summer burn. Periodic burn treatments were applied nearly

every 7 years, or when hardwood stems were approximately 2.5 cm d.b.h.

Soil Texture

Soil texture was measured on all plots in the study site because variations may alter retention and movement of nutrients through the mineral soil after burning.

Soil textures were found to be uniform across burning treatment plots for the Alabama, Florida, and Louisiana sites. A sand texture class was indicated for the Alabama site, with sand content from 79 to 82 percent and clay from 6 to 9 percent, and for the Florida site, with 89 to 91 percent sand and 5 to 6 percent clay. The Louisiana soil was considerably heavier, with a silt loam topsoil and a loam at 30 to 40 cm.

Mechanical analysis of the South Carolina soil indicated that texture varied with treatments. Sand content ranged from 47 to 56 percent, with greater amounts of sand on the periodic burn plots and the least amount on the annual summer burn plots for the 0- to 5-cm soil layer. The same relationship is found for the 5- to 10-cm layer, with sand averaging 51 percent. On the 15- to 20-cm layer, which generally represents the A2 horizon, sand ranged from 39 to 50 percent, with the control and annual summer burn plots having less sand than did other plots. Sand averaged 36 and 33 percent in the lower two soil layers.

Clay content was higher by 4 to 5 percentage points on the annual winter burn plots than on the control or periodic burn plots. Clay averaged 19 percent in the 5- to 10-cm soil layer, which indicated 6 to 7 percentage points higher clay levels on the control and annual summer burn plots than on the periodic winter burn plots. Clay averaged 38 percent in the 30- to 35-cm layer and 41 percent in the 45- to 50-cm layer, where the lower layer represents the B21t or B22t portion of the soil profile. Because of the apparent texture variation among burning treatments in the South Carolina study, texture is used as a covariant to compute total nutrient content on an area basis. The use of this covariant results in an improved test of treatment effects because it is assumed that the 30 years of prescribed burning did not alter texture and that the exchange capacity, organic content, and cation concentration are related to texture.

Sampling Methods

Each plot in the four studies was sampled at 40 points, with 10 sample points composited to make 4 samples per plot for each forest floor layer or soil horizon. Samples consisted of all material including L, F, and H layers collected from within a 15-cm square frame. The forest floor was mor humus that has little mixing with the mineral soil. No attempt was made to segment the forest floor by layers.

Two 2.5-cm soil cores were collected from within the square sample point. The cores were segmented into centimeter depths of 0 to 5, 5 to 10, 15 to 20, 30 to 35, and 45 to 50 on the South Carolina and Louisiana plots, and 0 to 8, 8 to 16, and 32 to 40 on the Alabama and Florida plots. The 0- to 5- and 5- to 10-cm sample depths represent the A1 horizon on the heavier soils and correspond to sampling depths made previously on these sites. The 15- to 20-cm depth represents the A2 horizon over the range of heavier soils. The 30- to 35- and 45- to 50-cm depths were selected to sample the B1 and upper B2 horizons. On the sandier soils, the 0- to 8-cm sample represents the A1 horizon. Because more movement of nutrients was expected on these sites, depth was increased to measure the burning response. The 8- to 16- and 32- to 40-cm depths represent the A2 horizon on these sites and were the lowest depths on which a measurable burning effect was expected.

Laboratory Methods

Forest floor samples were dried at 70° C for 24 h, weighed, and ground to

pass a 40-mesh screen. Nitrogen was determined with a modified micro-Kjeldahl procedure with 0.1 g of material digested in a test tube, and ammonia was determined by the salicylate-cyanurate procedure (Nelson and Sommers 1973). Other analyses were made on material dry ashed for 2 h at 450° C and taken up in 0.03 N HNO_3. Phosphorus was determined by the molybdovanadate procedure (Jackson 1958); potassium, calcium, and magnesium were determined by atomic absorption. A separate sample was dry ashed at 500° C for 2 h to determine mineral content, which was subtracted from the dry weight; thus, weights of forest floor material represent only loss on ignition component.

Soil samples were air dried and crushed to pass a 2-mm sieve. Organic matter content was assayed by wet oxidation (Jackson 1958), and particle-size distribution was determined by the hydrometer method (Day 1965). Exchangeable bases were determined by atomic absorption on extracts made with 1N NH_4OAC (Jackson 1958). Available phosphorus was determined by extracting 2.5 g of soil with 20 ml of Bray P2 solution (Bray and Kurtz 1945). Inorganic phosphorus was fractionated by the method of Chang and Jackson (1957), and organic phosphorus was determined by the procedure outlined by Olsen and Dean (1965) on samples with centimeter depths of 0 to 5 or 0 to 8. Total soil nitrogen was determined by micro-Kjeldahl digestion of a 1.0-g sample, and ammonia was determined by the salicylate-cyanurate method (Nelson and Sommers 1973). Soil pH was measured with a glass electrode on a 1:2 soil: water mixture.

Results are expressed as nutrient concentrations in soil components and as total content in surface soil and forest floor. Bulk density values are from previous measurements taken on the South Carolina study (Ralston and Hatchell 1971) and from typical profile properties of soil series involved on other sites (USDA SCS 1975-1980). Comparison of burning treatments within studies is made by analysis of variance, with significant differences reported at the 0.05 level.

RESULTS AND DISCUSSION

Mineral Soil Properties

Burning effects tended to be consistent over the range of Coastal Plain soils examined, with the degree of response reflecting soil properties of specific sites (table 1).

pH.--Soil pH increased slightly but significantly with degree of burning in the surface 0-8 or 0-5 cm layer on the Olustee and Santee burn studies. On the Olustee site, soil pH was 0.14 unit higher on the annual burn than on the periodic burn plots. On the South Carolina site, soil pH was significantly higher on the annual summer burn plots than on control or periodic winter plots by 0.4 unit. Periodic summer and annual winter burn plots had intermediate pH values which did not differ significantly from those on other treatments. On the Alabama site, prescribed burning did not significantly alter pH values; however, on burned areas, treatments averaged 0.2 to 0.3 pH units higher. At lower depths, burning had no apparent effect on soil pH values as measured in this study.

For a wide range of soils and burning techniques, soil pH has been shown to increase to some degree shortly after burning (Wells and others 1979). Normally, acidity increases with time after burning and soil pH returns to its preburning value. Degree of pH increase and time needed to return to the preburning level depend on burning intensity, amount of forest floor consumed, soil properties (including organic matter and clay content), rainfall, and internal soil drainage. Findings in this study indicate that periodic burn treatments had averaged pH values slightly higher than those of the control plots, demonstrating that pH increase following a burn is apparent for at least 7 years on heavier soils. The pH value for the periodic burn treatments on the sandy Florida soils did not differ from that of the unburned control, which suggests that pH increase had a shorter duration on this site--last burned 2 years before sampling.

Table 1.--Available nutrients and physical properties of mineral soil layers following prescribed burns on four study areas

Soil depth and burn treatment	pH	Total N	Avail. P	Exchangeable bases				Sand	Clay	Organic content
				K	Ca	Mg	Na			
	p/m			meq/100 g				percent		
BREWTON, ALABAMA										
0-8 cm										
Control	5.2	635	2.3	0.05	1.27B	0.20A	0.10	82	6	2.28
Biennial winter	5.4	770	2.4	.04	1.89A	.14B	.10	81	6	2.69
8-16 cm										
Control	5.4	377B	1.7	.02	.84	.08	.09	82	7	1.43
Biennial winter	5.4	483A	1.9	.02	1.10	.10	.09	81	7	1.37
32-40 cm										
Control	5.4	226	1.0	.02	.67B	.09	.09	81	7	1.00
Biennial winter	5.4	247	1.2	.02	.80A	.12	.09	79	9	.85
OLUSTEE, FLORIDA										
0-8 cm										
Control	4.1AB	1,028B	7.05B	.03	.25B	.22B	.09	89	6	3.72B
Periodic winter	4.0B	1,213AB	9.55A	.04	.45A	.35A	.10	89	6	4.81A
Annual winter	4.2A	1,317A	10.48A	.04	.57A	.38A	.08	88	6	4.55AB
8-16 cm										
Control	4.5	412	3.11	[a/].01A	.14	.08	.05A	91	5	1.48
Periodic winter	4.4	368	3.15	.01B	.15	.09	.04B	91	5	1.60
Annual winter	4.4	401	3.87	.01B	.15	.09	.03C	91	5	1.46
32-40 cm										
Control	4.8	315	8.94	.01A	.10	.04	.04A	91	5	1.17
Periodic winter	4.9	342	5.92	.00+B	.07	.04	.04A	91	5	1.07
Annual winter	4.9	428	7.56	.00+B	.06	.03	.03B	91	5	1.39
ROBERTS PLOTS, LOUISIANA[b/]										
0-5 cm										
Control	5.2	1,165	2.84	.08	2.96	.58	.09	43	9	4.17
Annual winter	5.5	1,123	3.02	.08	2.69	.96	.11	--	--	3.36
5-10 cm										
Control	5.5	637	1.39	.05	2.38	.42	.07	34	9	2.23
Annual winter	5.3	447	1.41	.04	1.19	.56	.18	28	12	3.33
15-20 cm										
Control	5.3	403	.62	.03	1.62	.47	.07	32	15	1.78
Annual winter	5.0	302	.64	.03	.55	.56	.22	27	17	1.99
30-35 cm										
Control	5.1	408	.24	.05	2.98	.96	.07	29	23	1.73
Annual winter	4.9	371	.35	.04	.49	.80	.25	24	24	1.80
45-50 cm										
Control	5.0	443	.22	.05	1.67	1.12	.08	33	12	1.49
Annual winter	5.0	363	.21	.04	.50	.83	.31	27	25	1.67

Continued

Table 1.--Available nutrients and physical properties of mineral soil layers following prescribed burns on four study areas--continued

Soil depth and burn treatment	pH	Total N	Avail. P	Exchangeable bases				Sand	Clay	Organic content
				K	Ca	Mg	Na			
	p/m			meq/100 g				percent		
SANTEE EXPERIMENTAL FOREST, SOUTH CAROLINA										
0-5 cm										
Control	4.1B	1,511	3.62B	0.07	0.63	0.28B	0.16	52	14	7.17
Periodic winter	4.1B	1,390	4.50AB	.07	.79	.33AB	.20	56	13	6.40
Periodic summer	4.2AB	1,695	5.02AB	.07	.87	.33AB	.19	54	17	7.72
Annual winter	4.2AB	2,221	5.45A	.09	1.23	.51A	.24	53	18	9.04
Annual summer	4.5A	1,721	4.13AB	.06	1.08	.38AB	.22	47	16	8.13
5-10 cm										
Control	4.5	705	1.41	.04	.31	.13	.14	49	19	8.00
Periodic winter	4.5	519	1.49	.04	.37	.13	.17	52	18	6.52
Periodic summer	4.6	711	1.74	.04	.45	.17	.18	55	19	8.16
Annual winter	4.2	943	1.99	.04	.45	.23	.23	50	21	9.15
Annual summer	4.6	746	1.46	.04	.54	.22	.21	49	17	9.81
15-20 cm										
Control	4.5	402	.61	.04	.39	.23	.15	39	29	1.46
Periodic winter	4.5	343	.77	.04	.37	.21	.15	50	22	1.28
Periodic summer	4.6	439	.92	.04	.41	.22	.17	49	25	1.51
Annual winter	4.4	417	.66	.03	.28	.21	.22	49	25	1.15
Annual summer	4.5	405	.70	.04	.44	.29	.22	40	28	2.18
30-35 cm										
Control	4.5	382	.19	.05	.47	.51	.17	33	40	1.14B
Periodic winter	4.5	292	.33	.05	.44	.41	.17	39	35	.78B
Periodic summer	4.6	437	.30	.05	.44	.41	.17	39	36	1.24AB
Annual winter	4.5	367	.18	.04	.35	.41	.22	34	40	.75B
Annual summer	4.4	420	.29	.04	.48	.42	.22	33	39	1.94A
45-50 cm										
Control	4.5	372	.07	.05	.54	.55	.19	30BC	44	.91B
Periodic winter	4.6	276	.11	.06	.45	.48	.19	36AB	38	.58B
Periodic summer	4.6	417	.15	.05	.40	.45	.18	37A	41	1.08B
Annual winter	4.4	382	.10	.05	.34	.45	.22	34ABC	44	.62B
Annual summer	4.4	411	.15	.05	.46	.45	.24	28C	40	1.83A

Values in columns for a given site and soil depth followed by different letters are significantly different at the 0.05 level.

[a/] Significance is based on values in the third decimal place.

[b/] Statistical analysis was not made because site does not have replication.

The pH values for surface soil following 65 years of annual burning on the Louisiana site are somewhat lower than those reported by Heyward and Barnette in 1934 (5.3 and 5.8 for the control and annual burn treatments) but similar to those reported by Murad and others (1979). These differences may result from variation in sampling season, depth of samples, and wildfire on the control plot before the last sampling. Samples collected after 10 years of burning on the South Carolina site averaged within 0.1 to 0.2 pH unit of the 30-year samples in both the 0-5 and 5-10 cm soil depths (Metz and others 1961). An exception is the annual winter plots with a pH value of 4.2, compared with 4.6 at 10 years.

Nitrogen.--In the mineral soil layers, an increase or at least no decrease of nitrogen was indicated from burning except on the nonreplicated Louisiana study, where less nitrogen was found on the burned plot. On the Alabama site, total nitrogen tended to be higher on burn plots at all depths, but the effect was significant only in

the 8-16 cm depth where burning increased total nitrogen by 106 p/m. Nitrogen levels averaged 699 and 237 p/m for the 0-8 and 32-40 cm depths. On the Florida site, total nitrogen concentration was 289 p/m higher on annual burn plots, compared with the control plots in the surface layer. The periodic burn plot did not differ from plots with other treatments. At lower depths, burning had no significant effect, with total nitrogen averaging 394 and 362 p/m at 8-16 and 32-40 cm. The burn and control plots on the Louisiana site had nearly equal nitrogen content in the 0-5 cm depth, where the highest concentration was found and the greatest effect of burning is generally indicated. The control plot was consistently higher at all depths with values of 37 to 190 p/m more nitrogen. The lack of replication of this historic prescribed-burn study is unfortunate.

Nitrogen content of the Louisiana site was reported as 740 and 860 p/m in the 0-5 cm soil layer for the burned and control plots 44 years earlier (Heyward and Barnette 1934). These earlier values are 31 to 44 percent lower than those found in the present sampling, which may reflect changes caused by growth of the tree stand and by wildfire on the control plot. Variation in techniques and sampling may also affect results. However, values at lower depths for the present analysis are 16 to 26 percent higher on the unburned control and 19 to 22 percent lower on the annual burn treatment, which suggests that there has been a substantial increase in nitrogen in the 0-5 cm layer for both treatments over time.

Total nitrogen concentration was not significantly affected by burn treatments and decreased with soil depth on the South Carolina site. Values averaged 1,708, 725, 401, 380, and 372 p/m in the five layers sampled. However, nitrogen content tended to increase with burning. A comparison of results to analyses made 10 and 20 years after the study was established is made in a later section.

Available phosphorus.--The amount of available phosphorus was higher for burn treatments on all four study sites. On the Alabama site, treatment effects did not differ significantly, but phosphorus levels were 0.1 to 0.2 p/m higher on burn plots. Available phosphorus averaged 2.4, 1.8, and 1.1 p/m in the three sample depths. Annual and periodic burns increased available phosphorus by 2.5 to 3.4 p/m in the 0-3 cm depth on the Florida site. Frequency of burning had no effect. At lower depths, with average values of 3.4 and 7.5 p/m, burning treatments did not affect phosphorus content. Sampling on the Louisiana site indicated that available phosphorus was 0.03 to 0.18 p/m higher on the burn plot in the surface layer but no discernible difference was found at lower depths. On the South Carolina site, available phosphorus increased with burning where annual winter burns increased available phosphorus by 50 percent over the control. Other treatments did not differ significantly from the control or annual winter burn. Phosphorus content below the surface averaged 1.62, 0.73, 0.26, and 0.12 p/m by sample depth for the five burn treatments.

Metz and others (1961), using a Bray P_2 extractant, report phosphorus ranging from 13 to 26 p/m, but they report values of 3 to 7 p/m when using a double acid extraction after 10 years. Wells (1971) reports phosphorus as a total quantity per acre but with values in the range of the present study after 20 years. Other investigations have also indicated that burning increased available phosphorus (Wells and others 1979). The effect of burning on specific chemical forms of phosphorus is reported in a later section.

Exchangeable potassium.--Potassium levels were not altered by burning treatments and were low, by agronomic standards, on all four sites. Exchangeable potassium averaged 0.04, 0.02, and 0.02 meq/100 g in the three soil layers on the Alabama site. Higher potassium content may be present

in the heavier clay subsoil underlying the surface sand on these soils. On the Florida site, the response of exchangeable potassium to treatment was similar to that of phosphorus. Either burn treatment resulted in a 0.01-meq/100 g increase. At lower depths, potassium averaged about 0.01 meq/100 g, with the control plots higher than the burn treatments. Potassium concentration would have to be carried to at least three decimal places to show this milliequivalent. Such precision is beyond the normal detection limits of the laboratory analysis. A contributing factor may be the slightly higher amount of clay on the control plots.

Exchangeable potassium was not influenced by burn treatments and averaged 0.06 to 0.09 meq/100 g in the 0-5 cm soil layer on the South Carolina and Louisiana sites. Lower soil layers had 0.03 to 0.06 meq/100 g of exchangeable potassium.

Exchangeable calcium.--On the Alabama site, burning increased exchangeable calcium in the 0-8 and 32-40 cm depths by 0.62 and 0.13 meq/100 g. The same trend is found at the 8-16 cm depth but differences are not significant. Similarly, on the Florida site the burned plots had 0.20 to 0.32 meq/100 g more exchangeable calcium than did the burn control. Calcium averaged 0.15 and 0.08 meq/100 g in the 8-16 and 32-40 cm depths over treatments.

In contrast to the other burn studies, calcium content on the Louisiana site was consistently higher on the control plot by 2.49 to 0.19 meq. Wildfire or inherent soil calcium concentration may be factors. Exchangeable calcium values reported for this site in 1934 by Heyward and Barnette were 0.19 to 1.46 meq higher than the present findings. Variations in sampling and extraction probably account more for these differences than do changes in the site from development of the tree stand.

Burn treatments did not significantly alter exchangeable calcium concentration on the South Carolina site, but calcium frequently tended to increase with increased burning in the 0-5 cm soil layer. Burning was found to significantly increase calcium for this site with the 10- and 20-year sampling (Metz and others 1961; Wells 1971). Values for exchangeable calcium 10 and 20 years after initiating burn treatments were within the range of the 30-year values and thus far do not indicate any trend over time in quantities of this nutrient in the mineral soil. Calcium averaged 0.42, 0.38, 0.43, and 0.44 meq/100 g at depths of 5 to 50 cm.

Exchangeable magnesium.--Generally magnesium responses to burning were similar to calcium responses. Exchangeable magnesium increased with burning by 0.06 meq/100 g in the 0-8 cm soil layer on the Alabama site. At lower depths, magnesium ranged from 0.09 to 0.10 meq/100 g and was unaffected by burning treatments. On the Florida site, magnesium content was 0.13 to 0.16 meq higher on the burn plots, compared with the control in the 0-8 cm soil layer. At lower depths, magnesium averaged 0.08 to 0.04 meq/100 g.

In contrast to exchangeable calcium, magnesium concentration on the Louisiana site was higher on the burn plot in the upper three sampling depths by 0.09 to 0.38 meq/100 g. At the lower two depths, the control plot had 0.16 to 0.29 meq more magnesium than did the burn plots.

The annual winter burn had 82 percent more exchangeable magnesium than did the control plot on the South Carolina site. Other burn treatments did not differ from the control or annual winter burn. Magnesium at lower depths averaged 0.18 to 0.47 meq/100 g and was not affected by burning treatment.

Exchangeable sodium.--Burning had no effect on exchangeable sodium for the Alabama, Louisiana, and South Carolina sites. Values ranged from 0.07 to 0.31 meq/100 g. On the Florida site, sodium content did not vary in the surface 8 cm of soil. At the 8-16 and 32-40 cm depths, however, ion levels were 0.01 and 0.02 meq higher on

the control plots than on the annually burned plots. At 16 cm the periodically burned plots had 0.01 meq more sodium than did annual burn plots but 0.01 meq less exchangeable sodium than did the control plots.

Organic matter.--Burning tended to increase the percentage of organic matter found in the surface 0-5 or 0-8 cm depth. On the Alabama site, burning effects were not significant; however, the biennial winter burn plots had 0.41 percentage points more organic matter than did control plots. Soils averaged 2.49, 1.40, and 0.93 percent organic matter in the 0-8, 8-16, and 32-40 cm soil layers. Periodic burning increased the percentage of organic matter in the 0-8 cm soil layer by 1.09 percent over the unburned plots on the Florida site. Annually burned plots did not differ from other treatments but averaged 0.83 percent higher than the control. Organic matter averaged 1.52 and 1.21 percent at the lower depths.

On the Louisiana site, organic matter was 0.81 percentage points higher on the control plot at the 0-5 cm depth but 1.10 percentage points higher on the burn plot at the 5-10 cm depth. Organic content decreased with depth but appeared to be higher on the burn plot by 0.07 and 0.21 percentage points. Values reported by Murad and others (1979) appear lower, partially explained by a sampling difference where a greater soil depth apparently is used. Comparison of amounts of organic matter on this site is further complicated by the wildfire 11 months earlier.

On the South Carolina site, amount of organic matter reflected treatments. Annual winter burn plots had 1.32 to 2.64 percentage points more organic matter than did periodic burn or control plots for the 0-5 cm depth, but differences are not significant. The same general relationship was found at 5-10 cm. Significant differences due to treatments were observed at 30 to 50 cm below the surface, where annual summer burn plots contained significantly more organic matter than did other treatments by 0.75 to 1.25 percentage points except at 30 to 35 cm, where annual and periodic summer burns were not significantly different. The only explanation for the significant differences between treatments at these depths is that texture, drainage, and soil development may have interacted in some way to induce them.

Organic matter content observed in the 0-5 and 5-10 cm depths after 10 years (Metz and others 1961) shows a trend similar to that of the 30-year results except that values averaged 0.6 to 2.7 percentage points higher at 10 years with wet combustion. The 20-year measurements (Wells 1971) were similar to those made at 30 years for the surface 10 cm of soil. The present findings further support Wells' observation that most of the organic matter changes resulting from fire occurred in the first 10 years. Organic matter on a total weight basis is discussed in a later section.

Phosphorus fractions in the surface mineral soil.--Phosphorus was fractionated into various chemical forms in the surface 5 to 8 cm to determine the effect of prescribed burning on the disposition of phosphorus in the mineral soil and its availability for plant uptake.

The water-soluble fraction of phosphorus represented 3 to 10 percent of total phosphorus present on the Alabama, Louisiana, and South Carolina sites (table 2). The Florida site, the only one showing a significant treatment effect, contained 33 to 34 percent of total phosphorus in water-soluble form, and periodic or annual burning significantly increased this by 24 to 29 percent. Except on the Louisiana site, burning tended to increase the water-soluble fraction by a small amount. Of interest is the relatively high level of the water-soluble fraction compared to total available phosphorus. Water-soluble phosphorus is extracted with normal ammonium chloride with a wide soil-solution ratio (1:50) and a 30-min shaking time. Thus, this fraction includes considerable loosely bound phosphorus that may not dissolve with a narrow soil-solution ratio and short mixing time.

Table 2.--Distribution of phosphorus in different chemical forms in the upper soil layer following burn treatments on four study areas

Site and burn treatment	Phosphorus fraction					
	H_2O	Al	Fe	Ca	Organic	Total
	- - - - - - - - - - - - p/m - - - - - - - - - - - -					
Alabama (0-8 cm)						
Control	2.9	0.4B	6.0	2.4	20.1B	31.7B
Biennial winter	3.0	.6A	6.3	2.2	23.3A	35.3A
Florida (0-8 cm)						
Control	10.7B	1.4	2.1	1.2	18.0	33.4B
Periodic winter	13.3A	1.7	2.5	1.4	21.6	40.6A
Annual winter	13.8A	1.7	2.7	1.1	21.2	40.5A
Louisiana (0-5 cm)[a/]						
Control[b/]	2.4	.5	7.4	.9	25.0	36.2
Annual winter	1.7	.3	12.5	3.3	30.0	47.8
South Carolina (0-5 cm)						
Control	4.4	4.3	15.2	2.7	52.1	78.0
Periodic winter	5.5	5.3	13.9	2.7	45.8	73.3
Periodic summer	4.8	5.4	12.4	2.4	53.0	77.9
Annual winter	4.8	5.1	17.0	2.9	56.4	86.3
Annual summer	4.5	4.2	16.7	2.2	51.6	79.2

Values for chemical fractions followed by the same letter or with no letter within study areas are not significantly different at the 0.05 level.

[a/] Statistical analysis was not made because site does not have replication.

[b/] Wildfire 11 months earlier.

Phosphorus in the aluminum form was less than the water-soluble fraction on all but the South Carolina site. Burning increased the aluminum phosphorus in the Alabama soil by 0.2 p/m. The same trend is apparent for the Florida soil but is not significant. The heavier Louisiana and South Carolina soils show no conclusive trend.

The iron phosphorus fraction accounted for 16 to 26 percent of total phosphorus on all but the Florida site, where the iron fraction represented 6 to 7 percent of the total. Phosphorus in the iron fraction tended to increase with burn treatments but not significantly.

Calcium phosphate represents 3 to 8 percent of total phosphorus present on the four sites. With the small amounts present (1 to 3 p/m), no apparent effect from burning was found.

Organic phosphorus accounted for 50 to 69 percent of total phosphorus in surface 5 to 8 cm of soil on the four sites. On the Alabama site, burning increased organic phosphorus by 16 percent or 3.2 p/m. On other sites, an apparent increase in organic phosphorus of 3 to 5 p/m was noted, but the increase was not significant. The amount of organic phosphorus was positively related to total phosphorus extracted from soils on these sites, accounting for 86 to 94 percent of the variation

between the two variables. Burning significantly increased total phosphorus (sum of the fractions collected) extracted from sandy sites in Florida by 4 to 7 p/m. No apparent difference is found between the annual and periodic burn on the Florida site. Burning also tended to increase total phosphorus on heavier soils, but the response was not significant.

The close relationship between total phosphorus and organic phosphorus in soil indicates the need to investigate this form of the nutrient and to increase its availability to higher plants.

Daughtrey and others (1973) found the release of organic phosphorus from Coastal Plain soil completely dependent on the activity of soil microorganisms in decomposing organic matter. Nutrient release with burning would accelerate the breakdown of organic matter and release of organic phosphorus to the soil solution. At least in Florida, water-soluble phosphorus decreases when organic phosphorus increases on plots burned; however, no attempt was made to determine if this is the effect of burning or later microbial breakdown. Accumulation of organic matter and organic phosphorus is probably the result of small, particulate matter being washed into the soil.

Forest Floor Properties

Organic content.--Prescribed burning predictably lowered the total weight and nutrient content on all four sites (table 3). The unburned control

Table 3.--Average weight of forest floor component following burn treatments on four study areas

Site and burn treatment	Organic content	N	P	K	Ca	Mg	Organic to N ratio
	kg/ha × 1000	kg/ha					
Alabama							
Control	13.86A	226A	8.7A	6.7A	67.2A	9.3A	61:1
Biennial winter	5.44B	27B	3.1B	2.9B	29.2B	3.5B	201:1
Florida							
Control	29.16A	131A	24.7A	29.1A	115.0A	21.0A	223:1
Periodic winter	9.52B	37B	6.7B	9.5B	40.0B	11.0B	257:1
Annual winter	4.54C	7B	3.0B	4.5B	19.0B	6.0B	649:1
Louisiana[a/]							
Control	39.81	307	11.8	14.0	206.0	24.6	130:1
Annual winter	22.15	127	6.8	13.1	103.0	14.0	174:1
South Carolina							
Control	26.27A	408A	17.4A	19.7A	126.0A	19.0A	64:1
Periodic winter	18.46B	300B	12.1AB	13.6AB	91.0B	19.0A	62:1
Periodic summer	17.56B	277B	10.6B	9.7B	77.0B	16.0AB	63:1
Annual winter	10.48C	156C	7.2B	6.2B	52.0C	11.0BC	67:1
Annual summer	10.05C	129C	7.1B	7.8B	48.0C	6.0C	78:1

Values for a given nutrient on individual sites followed by the same letter are not significantly different at the 0.05 level.

[a/] Statistical analysis was not made, and control plot was subjected to a wildfire 11 months earlier.

plots contained from 13 to 39 t/ha of organic matter. The high value for the Louisiana site would be expected to be even higher except for the wildfire on the area. Annual or biennial burning reduced the organic level of the forest floor by 44 to 84 percent on the Alabama site. Periodic burning on the Florida and South Carolina sites reduced the weight of the forest floor by 33 to 67 percent. Season of burning did not significantly affect total organic content.

Organic content of the forest floor is approximately the same for the control plot on the South Carolina site as reported 10 years earlier (Wells 1971). The forest floor contained 18.57, 26.88, and 26.27 t/ha for the 10-, 20-, and 30-year measurements on control plots (Metz and others 1961; Wells 1971). Thus, in terms of weight, the forest floor had reached an equilibrium between 10 and 20 years after initiating the study, when trees were about 45 years old. At 30 years, the forest floor contained 18 to 39 percent mineral material (determined by dry ashing the combined L, F, and H layer samples from the four studies).

On the South Carolina site, the L layer was segmented into pine, hardwood, and other partially unidentified material. The pine component increased in the litter layer from 56 to 65 percent with annual winter burning, while the hardwood component decreased from 22 percent on control plots to 6 and 12 percent on annual winter and summer burn plots. The balance of the L layer was not pine or hardwood and could not be separated.

Wells and Jorgensen (1975) found that forest floor biomass reaches its peak in loblolly plantations at about age 30 in Piedmont stands in North and South Carolina. The sites used in this study had considerably older trees with less needle production, but the loss in needles on the forest floor was probably compensated by litter from hardwoods or herbaceous species.

Nitrogen.--Nitrogen content in the forest floor decreased by as much as 95 percent with annual fires and 72 percent with biennial fires. Part of this nitrogen loss was from leaching water-soluble components and fine particulate from the forest floor into the soil. The forest floor of periodically burned plots had nitrogen losses ranging from 26 to 32 percent on the South Carolina site, which had not been burned for 5 years at sampling, to a 72 percent loss on the Florida site, which had been burned the previous year. Wells (1971) observed that the burning of the periodically treated plots on the South Carolina site 10 years earlier resulted in a nitrogen loss of about 112 kg/ha by volatilization. The 408 kg/ha nitrogen in the forest floor on the control appears to represent an "equilibrium" value for this nutrient under the conditions imposed by the stand and the climate (Wells and Jorgensen 1975). The other sites also represent near-equilibrium conditions except for the Louisiana site, which had been subjected to wildfire. Of interest are the nearly equal amounts of organic matter on the South Carolina and Florida sites but about a fourfold greater amount of nitrogen on the South Carolina site compared with the Florida site. The amount of nitrogen in the forest floor probably represents species and site conditions specific to each location.

The C:N ratio (organic matter:N) is a controlling factor in determining availability of nitrogen and potential decomposition of the forest floor. The ratio of organic matter to nitrogen widened by about onefold to threefold on the Alabama, Florida, and Louisiana sites following annual or biennial fires. The change was from 5 to 20 percent for the annual burns on South Carolina plots and was not noted on the periodically burned plots. An exact C:N ratio is difficult to obtain because much of the organic matter is charred after burning; however, the magnitude of change observed reflects an apparent nitrogen mobilization that cannot be explained by degree of carbon reduction. In all cases, a number of rains had fallen on all the burn plots between the time they were burned and sampled. Comparison of forest floor values on the South Carolina plots after 20 years shows a similar trend.

Heyward and Barnette (1934) observed that the L layer had a C:N ratio nearly two to three times wider than that of the F layer. Wells and Jorgensen (1975) observed a similar relationship for loblolly pine plantations in the Piedmont, where the C:N ratio of litter narrowed over time. Because it is primarily the L layer that is consumed by fire, it is surprising that burning results in a wider C:N ratio. Apparently low-intensity fires have a "mobilizing effect" on nitrogen in the F layer, which may in part account for the increased nitrogen concentration in the upper 5 to 8 cm of mineral soil. Burning may also cause some downward movement of nitrogen as a gas through a distillation effect (Tangren and McMahon 1976).

The explanation of nitrogen movement by this mechanism is supported by findings of Klemmedson and others (1962), who showed that burning accelerated nitrogen movement into the mineral soil. Light burning in ponderosa pine (P. ponderosa) stands caused movement of 12.4 kg/ha nitrogen per year into the surface 2.5 cm of mineral soil. Wells and others (1979) summarized a number of investigations which indicate that appreciable mobilization of nitrogen as well as volatilization of the forest floor occurs after burning.

Phosphorus.--The amount of phosphorus in the forest floor was reduced by 42 to 88 percent with biennial or annual burning on all four sites. Analysis indicates that most phosphorus accumulates in the surface 5 to 8 cm of soil on these areas (see table 1). Periodic burning resulted in a 39 to 73 percent decrease in phosphorus in the forest floor. On the South Carolina site, phosphorus was reduced by periodic summer burns but not by periodic winter burns. The season of periodic or annual burning did not affect phosphorus loss, and there was no significant difference between annual and periodic fires.

Potassium.--Potassium in the forest floor ranged from 6.7 to 29.1 kg/ha and was reduced by 6 to 69 percent with biennial or annual burning on the four sites. Periodic burning reduced potassium by 67 percent on the Florida site and by 51 percent for summer fires on the South Carolina site. Results of the periodic winter fire on the South Carolina site were not significantly different from those of the unburned control. Considering that 98 kg/ha of potassium were reported to be in the plantation forest floor at age 20 (Switzer and Nelson 1972), amounts in the present sampling are relatively low, which reflects the high mobility of the element.

Calcium.--Calcium in the forest floor was reduced by 50 to 92 percent with annual or biennial burning. Periodic burning did not reduce calcium significantly on the Florida site but resulted in a 28 to 39 percent reduction on the South Carolina site. Season of burning had no effect on calcium content for this site. Thus, prescribed burning accelerated the rate of calcium returned to the soil mineral system. This movement probably resulted from cations moving in the soil solution, but ash conduction may also be a factor. Wells and Jorgensen (1975) indicate that without burning calcium loss compared to potassium or magnesium loss is slow and that after 8 years appreciable portions of the nutrient remain in the forest floor from a given year's deposition. Quantitatively, 50 percent of the magnesium from a given year's accumulated litter is lost from the forest floor in less than 1 year, while 3 years are required to obtain this degree of calcium mineralization (Jorgensen and others 1980).

Magnesium.--Amounts of magnesium in the forest floor were approximately one-fourth to one-tenth those of calcium. The mobilization of magnesium with burning appears similar to that of calcium, and 43 to 71 percent magnesium was lost from the forest floor with biennial or annual burning. Periodic burning on the Florida site reduced magnesium by 48 percent. Periodic burning and season of burning did not significantly affect the South Carolina site. Based on values reported by Wells and Jorgensen (1975) for loblolly

pine in the Piedmont, the forest floor on these sites contained about one-half to one-third the magnesium in the tree biomass, and the nutrient would be expected to move out of the floor faster than calcium.

TOTAL NUTRIENT CONTENT OF STUDY AREAS

Total nutrient content of the four study areas, by treatment, is estimated for the mineral soil layers sampled, with results expressed as kilograms per hectare.

Bulk density values reported by the Soil Conservation Service (USDA SCS 1975-1980) are used to estimate the amounts of nutrients in the surface 40 to 50 cm of soil (table 4). Burning treatments appear to have had little effect on nutrients when the entire profile is considered. Total nitrogen ranged from 1,800 to 4,500 kg/ha. Higher values are associated with the heavier mineral soils on Louisiana and South Carolina sites but also represent profiles of 50 cm of soil compared to 40 on the Alabama and Florida sites. Here, amount of available phosphorus was reversed, with greater amounts on sandy soils, ranging from 25 to 38 kg/ha. The heavy soils averaged 4 to 7 kg/ha of available phosphorus. In the deeper sampled profiles, the surface 5 to 8 cm of mineral soil contained 22 to 52 kg total phosphorus, with greater amounts on the heavier soils of the South Carolina site.

Among the four sites, exchangeable potassium ranged from 25 to 135 kg/ha. Exchangeable calcium ranged from a high of 3,250 kg/ha on the Louisiana site to a low of 130 kg/ha on the Florida site. Exchangeable magnesium ranged from 40 to 670 kg/ha, with the low and the high again on the Florida and Louisiana sites. Cation levels appear to reflect soil texture changes with higher levels found with heavier soils.

Because effects of burning are not readily apparent when comparisons are based on whole-profile samples and effects are greatest in the upper lay-

Table 4.--Estimated total nutrients in mineral profile sampled for the four burning studies

Site and burn treatment	N	P	K	Ca	Mg
			kg/ha		
Alabama (0-40 cm)					
Control	1,800	32	44	770	55
Biennial winter	2,100	38	47	1,050	75
Florida (0-40 cm)					
Control	2,200	25	25	130	40
Periodic winter	2,400	28	29	140	55
Annual winter	2,800	30	29	160	55
Louisiana (0-50 cm)					
Control	4,500	6	98	3,250	670
Annual winter	3,850	7	81	3,050	615
South Carolina (0-50 cm)					
Control	3,520	4	125	700	360
Periodic winter	2,960	6	135	650	325
Periodic summer	3,700	6	126	630	295
Annual winter	3,240	5	115	570	315
Annual summer	3,680	5	115	710	320

ers, nutrient quantities are compared by using only the surface 10 to 16 cm of mineral soil and forest floor (fig. 1). A mineral soil depth of 10 cm is used for the heavier soils of the Louisiana and South Carolina sites and 16 cm for the sandy Alabama and Florida soils. Bulk density for the Louisiana soils is reported by Murad and others (1979); for South Carolina soils, by Ralston and Hatchell (1971); for Florida soils, by L. J. Metz;[1] and for Alabama, typical soil series densities as reported by the Soil Conservation Service were used (USDA SCS 1975-1980).

Organic Matter

Burning reduced the organic content of the forest floor but not in the mineral soil; in fact, though not statistically significant, an increase is observed (fig. 1). The result is a rather small total loss of carbon from the system due to burning part of the forest floor. The poorer drained soils in Florida and South Carolina appear to have higher organic content in mineral soils than those of the Alabama or Louisiana sites. Surprisingly, the Louisiana unburned plot retained a large amount of organic matter in the forest floor despite wildfire.

Nitrogen

The sandy Alabama and Florida sites show a slight increase in nitrogen in the total system with burning despite a marked loss from the forest floor after 8 to 20 years. The Louisiana plots contrasted with the other sites where 160 kg more nitrogen is found on the unburned control compared to the burn plot. Without replication and following wildfire on the control plot, no explanation for this effect is possible.

The South Carolina study had been sampled after 10 years (Metz and others 1961) and 20 years (Wells 1971). The findings, corrected by covariant analysis with clay as the covariant, are compared with current results in terms of total nitrogen in the 0-10 cm mineral soil layer and forest floor (table 5). Over the 20-year period total nitrogen changed little in the unburned control and periodic winter burn treatments. For these treatments the 20-year increase of 34 to 42 kg/ha represents a 4 percent change. The periodic summer burn resulted in a 128-kg nitrogen loss. The annual winter burn increased total nitrogen by 137 kg. The striking effect was in the annual summer burn plots, where there was a 362-kg nitrogen loss. Since both summer burns resulted in total nitrogen losses, summer burning apparently has a detrimental effect on the amount of nitrogen remaining in the surface mineral soil, while winter burning increases the nitrogen. The exact cause is difficult to explain but may be related to the number of nitrogen-fixing legumes that invade these treatment sites following burns (Lewis and Harshbarger 1976).

Phosphorus

Without burning, appreciable quantities of phosphorus are tied up in the forest floor on all four sites (6 to 24 kg/ha). The amount of phosphorus in the mineral soil is difficult to relate to that in the forest floor primarily because only available phosphorus was used for the comparison, and nonsoluble forms in the chemical extraction do not appear. The test for available phosphorus is apparently sensitive to the burning treatment, with increased phosphorus found after burning; however, the quantities found do not relate well to frequency of burning or comparative reductions of phosphorus in the forest floor. A standard chemical test suitable for all sites is difficult to select because of the numerous chemical forms of phosphorus present.

When phosphorus forms in the soil are compared to tree growth, another problem is apparent regarding predicted

[1] Personal communication. Research Triangle Park, NC: Southeastern Forest Experiment Station; 1980.

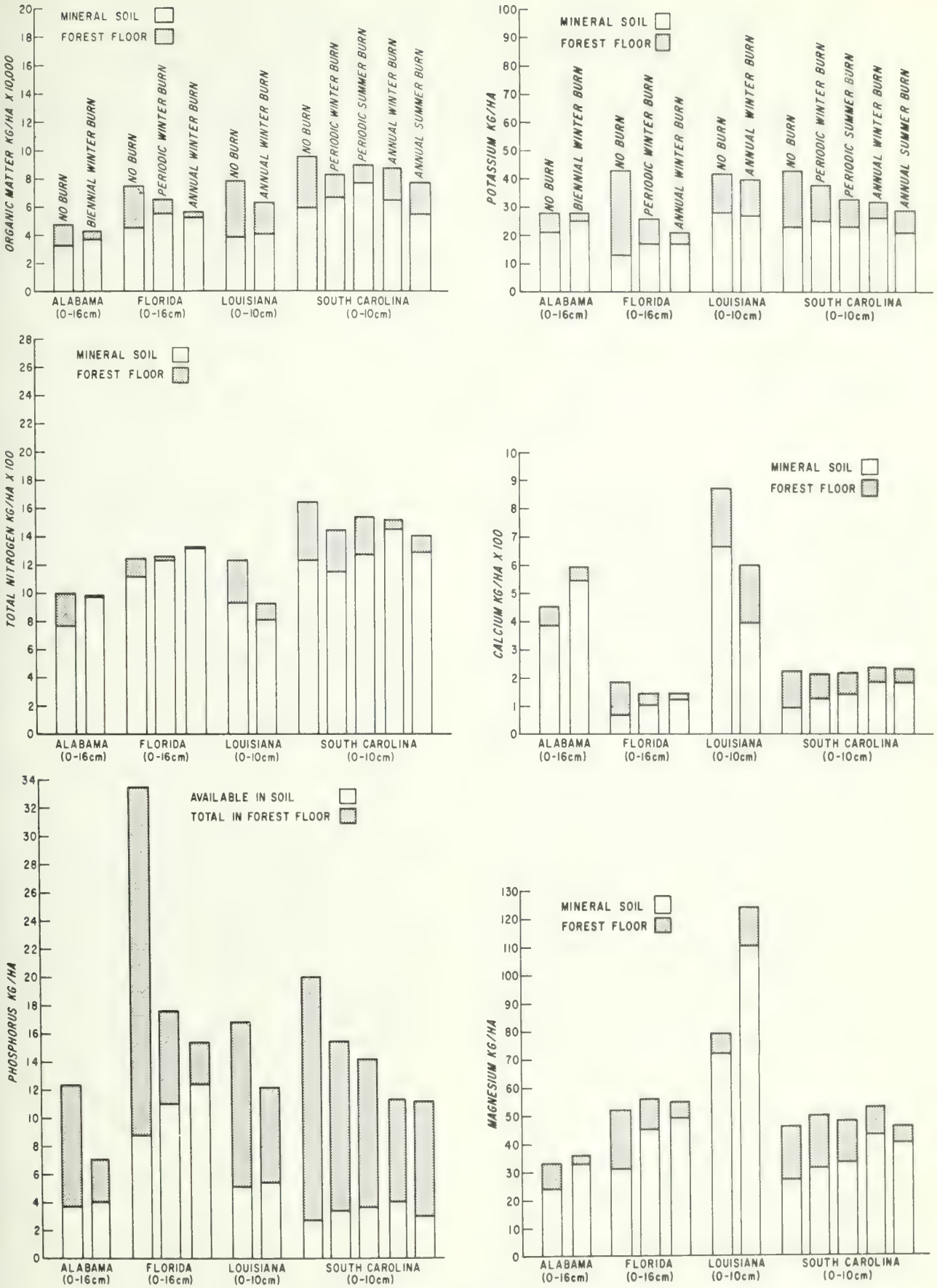

Figure 1.--Average weight of organic matter and nutrients in the forest floor and surface mineral soil on four study sites.

Table 5.--Changes in nitrogen content in the surface 10 cm of mineral soil following burn treatments in the South Carolina study

Burn treatment	10-year measurement	20-year measurement	30-year measurement	20-year gain or loss
	- - - - - - - - - - - kg/ha - - - - - - - - - - -			
Control	1,155	1,094	1,197	+42
Periodic winter	1,059	1,090	1,093	+34
Periodic summer	1,403	1,278	1,275	-128
Annual winter	1,403	1,509	1,540	+137
Annual summer	1,641	1,471	1,279	-362

long- or short-term responses, where the water-soluble fraction best defines short-term response and a "stronger acid" extraction works better for longer periods (Ballard and Pritchett 1974). The phosphorus fractions were not run on the 5-10 or 8-16 cm soil layers. Total mineral phosphorus in the 0-5 or 0-8 cm depths does not balance completely with the forest floor and in most cases does not reflect burning treatments. Prescribed burning did not consistently result in an increase in any one fraction of phosphorus in the surface mineral soil as found with available phosphorus. Rather, accumulation appears to depend on mineral, drainage, or other inherent soil factors. However, it is apparent that prescribed burning accelerates the cycling of phosphorus and benefits sites that are at least marginally deficient in the nutrient, which is significant for planning future timber rotations where phosphorus is limiting.

Potassium

The trends shown in figure 1 indicate a reduction of 12 to 20 kg/ha of potassium on the Florida and South Carolina sites as a result of burning. Other sites indicate little change. The Louisiana site may be atypical as a result of the wildfire on the control plot. Because all of these soils are characterized by weakly charged ex change sites, potassium probably cycl through a much larger portion of t profile. In addition, potassium mobile within plants and may be r tained in larger quantities in veget tion on burned plots. Thus, with p tassium movement out of foliage befo needle fall, this element will not completely cycled through litter fa (Pritchett 1979).

Calcium

Except on the Louisiana site, t forest floor and 10 or 16 cm surfa soil layer appear to represent a "co plete cycling" of calcium in the fore floor and mineral soil system wi burning treatments. Without burnin 16 to 61 percent of the calcium was the forest floor. With burning, 4 16 percent of the calcium present w in the litter layer. These changes deposition of calcium logically accou for pH increases in the mineral so associated with burning, and indicate long-term effect on soil acidity. T amount of calcium in the forest flo decreased proportionally to the fr quency of the burning in the Flori and South Carolina studies. T earlier calcium extraction in the Sout Carolina study (Wells 1971) show similar results, indicating litt change in the calcium status of th

site in the last 10 years. In the Louisiana study, there appears to be little relationship between values reported in 1934 and present values. Earlier results indicated 565 kg/ha of calcium in the mineral soil on the unburned plot and 687 kg/ha on the annually burned plots. The earlier sampling included two additional plots (Murad and others 1979) that have since been abandoned and which may reflect differences in the two data sets.

Magnesium

In the forest floor soil system, magnesium responds similarly to calcium, where 28 to 40 percent of the magnesium remains in the forest floor without burning and 11 to 16 percent remains with annual burning. On the Louisiana site, the burn plot had less calcium but more magnesium in the forest floor and soil system. Without replication, however, it is difficult to relate this effect to the burning treatment. Values found after the last measurement on the South Carolina site appear similar to those obtained by Wells (1971) 10 years earlier.

LONG-TERM EFFECTS OF PRESCRIBED BURNING

Heyward (1937) observed that the elimination of burning on Coastal Plain pine sites resulted in abrupt change in visual characteristics in a soil profile. The interpretation is that exclusion of burning accelerates soil weathering or development. With certain moisture and parent material factors, the end result would probably be a spodosol without fire and no spodic horizon with fire. Specific reports of fire thus affecting soil formation could not be found. It appears that the natural evolutionary pattern of soil development caused by water-soluble carbon, as observed by Herbauts (1980), at least can be moderated by burning. This conclusion is based on lysimeter studies on soils under forest cover where the degree of soil weathering was found to relate to the amount of soluble carbon moving through the profile. Nutrient movement from ash material following burning is alkaline (Raison and McGarity 1978), at least until the ash has dissolved and moved into the mineral soil. To some degree, burning destroys the substrate and either consumes or volatilizes organic acids produced in the forest floor. Such change is assumed to be roughly proportional to the reduction of organic matter consumed in the burning. The water-soluble carbon has been described as humic and fluvic acid (De Kimpe and Martel 1976), carbonic acid (McColl 1971), or other soluble organic acids. Where sulfur dioxide is a problem in "acid rain" from burning fossil fuels, the resulting sulfuric acid is a much larger factor than carbonic acid (Cronan and others 1978). The acid radicals react with the soil to form salts with alkali, alkali earth, and amphoteric metals that leach through the soil horizons in the process of weathering.

Yaalon and Yaron (1966) indicate that any man-caused activity such as adding fertilizer or changing the pH will change the metapedogenetic processes that retard podsolization; the rate of change depends upon the intensity of treatments. Bidwell and Hole (1965) also discuss a series of human practices as a dominant factor in altering soil formation by controlling organic matter through prescribed burns. Thus, burning pine sites on the Coastal Plain tends to maintain soils in a less weathered state and probably in a better tilth. Historically, such has been the case for much of the Coastal Plain with the maintenance of a fire climax ecology.

Another indication of the degree of soil development or weathering is the ratio of exchangeable magnesium to calcium (Buol and others 1973). As soils become more weathered, the ratio of calcium to magnesium narrows with higher magnesium and lower calcium levels. A comparison between magnesium and calcium in the surface 5 to 8 cm of soil on the sites studied is shown in table 6. Except for the Louisiana study, the ratio of magnesium decreased with burning by 26 to 129 percent. The degree of change in the ratio appears

Table 6.--Magnesium to calcium ratio in surface 5 to 8 cm of soil after prescribed burns on four study areas

Burn treatment	Alabama	Florida	Louisiana	South Carolina
Control	0.16	0.88	0.20	0.44
Periodic winter	--	.77	--	.42
Periodic summer	--	--	--	.38
Biennial winter	.07	--	--	--
Annual winter	--	.66	.36	.41
Annual summer	--	--	--	.35

to reflect the frequency of burning in the Florida and South Carolina studies. Within the period of these studies, this effect is found only in the surface A1 horizon. Burning did not change the ratio of exchangeable magnesium to calcium at lower depths. Over an extended period, the effect of the accumulated forest floor or presence of organic acids and leaching of cations from the upper horizon--as observed by Herbauts (1980)--would appear at lower depths, including the B horizon. In any case, prescribed burning apparently slows the process of soil weathering and may help maintain soil productivity at a higher level. A final proof of this hypothesis would require a time-span approaching several hundred years.

A more immediate problem, as proposed by Lyle and Adams (1971), is a nutrient imbalance caused by higher concentrations of magnesium than of calcium. These authors observed that because of "mass action effects," magnesium in excess of calcium results in reduced loblolly pine root growth. According to this concept, the surface soil layer in the unburned Florida treatment is nearing this condition while that in the other burn treatments in this study is not. Such relationships also may be important to microbial processes found on pine sites. Predictions of long-term effects of prescribed burning on nitrogen are more difficult; however, measurements made over 20 years on the South Carolina site and 44 years on the Louisiana site indicate that winter burning may actually increase total nitrogen in the mineral soil. Regardless, there is no detectable nitrogen loss from the mineral soil except perhaps with summer fires. Several timber rotations would be required to show a pronounced effect of fire on nitrogen with the rather larger amounts of total nitrogen present (2,000 to 5,000 kg/ha) in the mineral soil.

Prescribed burning of most Coastal Plain sites will not cause a serious leaching problem for phosphorus, and the more rapid mineralization and cycling of the nutrient where it is limited will help avoid a deficiency. Potassium, because of its high mobility, probably is relatively unaffected by burning on most sites. Analysis of the sites studied over time suggests no consistent effect of burning on exchangeable potassium.

CONCLUSIONS

The most striking result of this study is the similarity of burning effects on soil properties despite obvious soil differences and probable differences in burning techniques. All the burning is reported to be low-temperature flank fires or backfires except for the Louisiana study,

which--at least in early years--was reportedly burned with a headfire. The type of burn used plus wildfire that burned the control plot make observations of the Louisiana study difficult to interpret.

Organic matter consistently builds up faster in mineral soil on the burned treatments, and burning does not reduce total nitrogen except in the forest floor, where the decrease for annual burning was 280 kg/ha after 30 years in South Carolina. Total nitrogen in the surface 40 to 50 cm of mineral soil and forest floor ranged from 2,000 to 4,800 kg/ha on the four sites. On the unburned control plots, 6 to 11 percent of the nitrogen was in the forest floor. Annual burning reduced total nitrogen in the forest floor from 12 to 52 percent of the unburned treatments over the range of sites, but burning did not appear to reduce total nitrogen for the mineral soil on the burn plots over time; however, a balance sheet for the studies requires nitrogen data for the vegetation which may be causing an increase in nitrogen. While winter burning appears to increase total nitrogen in the mineral soil, summer burning appears to have a slightly deleterious effect. This observation needs to be expanded by sampling a number of sites.

Available phosphorus in mineral soil consistently increased with prescribed burning, which suggests that this may be one of the most beneficial effects of the treatment. No consistent pattern was found for burning effects on phosphorus fractions. The nature of compounds formed apparently represents specific pH conditions and mineral components in the soil. However, in all cases the burning obviously accelerated mineralization.

Except for the Louisiana study, the cation responses were quite similar. Potassium showed little effect from burning and appears to cycle in a soil mass larger than the 10-16 cm depth used for comparison. The soil depth used appeared to represent complete cycling of calcium. Trends indicted that the forest floor immobilized a large portion of the ion and in some cases altered the nutrient balance of the soil. Magnesium and calcium responded to burning treatments similarly, but their ratios indicate that magnesium appeared to recycle faster or at least to accumulate in mineral soil in the absence of burning.

It is apparent that burning will alter soil formation and long-term productivity over time. Evidence suggests that burning may improve soil by retarding soil weathering and, probably, formation of spodic layers in the profile. Further evidence of this observation would probably require five to six rotations of pine to compare soil development with and without fire.

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McKee, William H., Jr.
Changes in soil fertility following prescribed burning on Coastal Plain pine sites. Res. Pap. SE-234. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1982. 23 p.

Four prescribed burning studies were sampled to determine the effect of treatments on nutrient cycling and availability. Burning did not lower the level of available nitrogen in the mineral soil and accelerated cycling and availability of phosphorus and calcium.

KEYWORDS: Forest soils, forest floor mineral cycling, soil development, Pinus palustris, P. elliottii, P. taeda, phosphorus fractions.

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Multiresource Inventories--Forest Biomass in Florida

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Southeastern Forest Experiment Station
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Multiresource Inventories--Forest Biomass in Florida

by

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Forest Resources in the Southeast
Asheville, North Carolina

Abstract.--Florida's 15.7 million acres of timberland support 864 million tons of forest biomass, or an average of 55.2 tons per acre. This total exceeds the green weight of conventional growing stock by 73 percent. More than 38 percent of the biomass is in stands where wood could be harvested for energy in harmony with conventional forestry practices. Over the next 2 decades, about 14.0 million tons of forest biomass could be harvested annually without adversely affecting timber supplies.

Keywords: Growing stock, commercial forest land, multiple use.

Traditionally, state and regional forest inventories have been designed to estimate the volume of wood in trees 5.0 inches and larger in diameter at breast height (d.b.h.), from a 1-foot stump to a 4.0-inch top diameter outside bark (o.b.). Recently prepared statistical reports for Florida focus primarily on volume of growing-stock timber measured to these standards (Bechtold and Knight 1982; Sheffield 1980a, 1980b, 1981; Sheffield and Bechtold 1981). Because of the growing interest in forest biomass as a source of energy, however, the amount of additional wood and bark in all trees on commercial forest land also must be analyzed.

In such an analysis, the needs and concerns of the forestry community must be recognized. Forest managers are interested in any opportunity to rid timberland of vast quantities of wood and bark in low-quality trees. They are concerned, however, that extensive use of wood for energy would jeopardize supplies of growing stock counted on for other products. Much depends upon whether wood is viewed as a temporary or long-term source of energy. Since the long-term demand for biomass for energy is uncertain, it is difficult to differentiate between energy wood and growing stock. The quantity, composition, distribution, and prospective availability of all forest biomass must therefore be evaluated.

In this Paper, we define forest biomass as the green weight of wood and bark on commercial forest land in all live trees 1.0 inch d.b.h. and larger from the ground to the top of the tree--excluding foliage. For trees 5.0 inches d.b.h. and larger, lateral limbs, secondary limbs, and twigs less than 0.5 inch at their base are not included. Foliage includes leaves and needles on trees 1.0 inch d.b.h. and larger, plus the wood and bark in lateral limbs, secondary limbs, and twigs less than 0.5 inch in trees 5.0 inches d.b.h. and larger.

This Paper contains estimates of: (1) total biomass as defined, (2) biomass of conventional growing stock, including bark, and (3) biomass that appears suitable for energy wood in Florida and could be harvested in harmony with conventional forestry practices and opportunities for enhancing future timber growth. It also identifies new opportunities for refining and studying forest yields, timber utilization, and successional trends.

METHODS

The 1980 multiresource inventory of Florida provided a full array of biomass data from all lands in Florida (Cost and McClure 1982). This Paper, however, is confined to commercial forest land. In commercial forest, numbers of trees, sizes, and quality were recorded at each sample plot. Trees 5.0 inches d.b.h. and larger were measured at 3 to 5 points where variable-radius plots were defined by a prism with a basal area factor of 37.5. Trees less than 5.0 inches d.b.h. were tallied on 1/300-acre plots around the point centers. These sample counts were expanded to represent the total population of trees on land classified as commercial forest. Volume equations based on detailed measurements of standing and felled trees in Florida and on similar measurements taken from other trees throughout the Southeast were used to compute merchantable and total cubic volume (Cost 1978). Weight equations provided by the Utilization of Southern Timber Research Unit of the Southeastern Forest Experiment Station in Athens, Georgia, made it possible to convert volume to weight. The procedures used for collecting and reporting detailed biomass data were outlined by Saucier (1979) and Clark (1979).

In the 1980 inventory, tree measurements and forest conditions were recorded at 4,680 ground sample locations systematically distributed throughout the State's 15.7 million acres of commercial forest. Information developed from this inventory provides the basis for this evaluation of forest biomass.

In the statewide timber evaluation, Florida's forests were described in terms of six broad management classes: (1) nonstocked forest, (2) pine plantation, (3) natural pine, (4) oak-pine, (5) upland hardwood, and (6) lowland hardwood. Nonstocked forest is commercial timberland less than 16.7 percent stocked with growing-stock trees. The other broad management classes were based on forest type, determined by the stocking of all live trees. In all stands where pines made up a plurality of the stocking, the broad management class was either pine plantation or natural pine. Stand origin distinguished between these two classes. Where there was evidence of planting or artificial regeneration, the stand was classified as a pine plantation. Oak-pine was the classification assigned to stands where hardwoods accounted for a plurality of the stocking but in which pines made up 25 to 50 percent of the stocking. In all other stands, hardwoods, cypress, palm, or other tropicals accounted for a plurality of the stocking, and forest type was used to distinguish between upland and lowland hardwood. Oak-hickory and scrub oak types were classified as upland hardwood; oak-gum-cypress, elm-ash-cottonwood, palm, and other tropical forest types were classified as lowland hardwood.

Since assignment of forest types is based on the stocking of all live trees, except those overtopped, rather than on the stocking of growing-stock trees, the broad management classes are even more meaningful in the evaluation of biomass. In this study of biomass, the broad management class "nonstocked forest" used in the timber evaluation was distributed among the other classes, based on forest type. Although these stands are nonstocked, based on growing stock, many contain substantial amounts of biomass in rough and rotten trees.

Acreage of commercial forest land, by broad management classes, was broken down into stand age classes. Since very little merchantable-size timber accrues in a stand before age 15 and many pine stands are managed on 30-year

rotations, 15-year age classes were selected for this analysis. The stand age data were collected to the year rather than in classes; therefore, any age class could have been selected. We acknowledge difficulties in determining a meaningful age in some natural stands. An understanding of these difficulties is important to the interpretation and use of some of the empirical yields of forest biomass presented in this report.

Often natural timber stands are a mixture of residual trees from a former stand and of younger trees established following the most recent harvest or disturbance. In these cases, field crews recorded the average age of trees of common origin which accounted for a plurality of the stocking as long as they were of sufficient number to form a manageable stand for timber production--normally 60 percent or more of the minimum number required for full stocking. Where insufficient trees of common origin were present for a manageable stand, the age was based on all trees present.

Finally, the acreage within each broad management class was further broken down by site and stocking classes. The stocking classes were based on all live trees rather than on growing stock. Average green weight of forest biomass per acre was compiled for each subdivision. The weight equations used were sensitive to species, d.b.h., and total height. There may be additional variation in weight attributable to geographical differences, stand origin (planted vs. natural), or tree section that would not be reflected in this study.

RESULTS AND DISCUSSION

Quantities of biomass are highly dependent upon the acreage of commercial forest, age of stands, and concentration of material on these acres. To assess distribution, composition, and prospective availability of forest biomass in Florida, it is helpful to know commercial forest acreages in terms of broad management and stand age classes. Table 1 shows a large concentration of pine plantations between 0 and 30 years old and natural pine between 15 and 45 years old.

During the late 1950's and early 1960's, extensive acreage was planted under the Conservation Reserve Soil Bank Program. During this era, extensive acreage of idle cropland reverted naturally to pine stands. Since about 1970, Florida has experienced a sharp reduction in acreage of idle cropland rotating back to forest. Also, tree planting on old fields decreased sharply following the termination of the Soil Bank Program. The acreage figures for pine plantation and natural

Table 1.--Area of commercial forest land, by broad management and stand age class, Florida, 1980

Broad management class	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Acres					
Pine plantation	3,282,193	1,578,767	1,604,891	80,843	17,692	0
Natural pine	4,487,331	531,800	1,354,814	1,450,794	859,716	290,207
Oak-pine	1,424,133	247,261	313,165	439,370	270,502	153,835
Upland hardwood	2,133,271	572,982	426,191	576,775	328,586	228,737
Lowland hardwood	4,337,249	335,374	522,654	1,012,338	1,116,801	1,350,082
All classes	15,664,177	3,266,184	4,221,715	3,560,120	2,593,297	2,022,861

pine in table 1 reflect these changes in land use.

For the oak-pine and upland hardwood stands, the greatest concentration is in the age class 30-44. Many of these stands are on sites that previously supported pine, but where the pine was not adequately regenerated at time of harvest.

Lowland hardwoods occupy 67 percent of all stands 60 years and older. Most of these stands are in Central and South Florida and occur in swamps and along the flood plains of rivers and streams. Accessibility is a problem in many of these stands, and management of these forests is a difficult challenge.

Total Biomass and Biomass of Conventional Growing Stock

One of the major objectives of this study is to determine the proportion of total biomass that is not considered to be conventional growing stock, including bark. Weight of conventional growing stock is the weight of wood and bark associated with the bole portion of growing-stock trees 5.0 inches d.b.h. and larger, from a 1-foot stump to a 4.0-inch top d.o.b. For the 15.7 million acres classified as commercial forest land, green weight of conventional growing stock averaged 31.9 tons per acre (table 2). Green weight of total forest biomass averaged 55.2 tons per acre, or 73 percent more (table 3). By broad management class, the largest difference between average weight of conventional growing stock and total forest biomass per acre was found in hardwood stands. In upland hardwood stands of all ages combined, average weight of total forest biomass exceeded the average weight of conventional growing stock by 23 tons per acre, or 138 percent. In lowland hardwood stands, the difference averaged more than 39 tons per acre.

Table 2 provides measures of the average accumulation of biomass within each broad management class over time. As one would expect, conventional growing stock accumulates somewhat faster in pine stands, especially pine plantations, than in oak-pine and hardwood stands. Control over both species composition and spacing in pine plantations shortens the time required to grow merchantable timber products. By broad management class across all age

Table 2.--Average green weight of conventional growing stock[a] per acre of commercial forest land, by broad management class, and stand age class, Florida, 1980

Broad management class	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Pine plantation	17.9	2.5	31.4	46.8	b	b
Natural pine	34.1	3.0	23.3	43.0	48.2	55.9
Oak-pine	28.7	4.0	18.5	35.7	43.3	43.6
Upland hardwood	17.0	2.9	10.5	18.9	28.4	43.6
Lowland hardwood	48.7	5.5	18.0	35.5	53.0	77.5
All classes	31.9	3.1	24.0	36.1	46.9	68.0

[a]Includes wood and bark between a 1-foot stump and 4-inch top d.o.b. in growing-stock trees 5.0 inches d.b.h. and larger.

[b]Sample was too small to provide a reliable estimate.

Table 3.--Average green weight of forest biomass per acre of commercial forest land, by broad management class, and stand age class, Florida, 1980

Broad management class	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Pine plantation	32.8	10.0	53.0	68.0	a	a
Natural pine	47.8	6.3	36.3	59.6	63.9	71.6
Oak-pine	51.1	12.2	37.8	61.2	68.9	80.4
Upland hardwood	40.4	13.1	30.2	43.7	62.4	87.7
Lowland hardwood	88.3	17.8	44.9	74.0	94.9	127.7
All classes	55.2	10.9	43.2	61.5	77.6	111.5

[a]Sample was too small to provide a reliable estimate.

lasses, average weight of conventional rowing stock ranged from a low of 17.0 ons per acre in upland hardwoods to a igh of 48.7 tons per acre in lowland ardwood stands.

Table 3 shows that lowland hardwood stands keep pace with the more intensively managed pine plantations in production of total forest biomass. Seemingly up to age 45, which is as far as the data permit comparisons, forest biomass accumulates faster in lowland hardwoods 0-14 and 30-44 years old than in pine plantations of comparable age. The low overall average for pine plantations is attributed to the large proportion (97 percent) of these stands that are less than 30 years old. On the other hand, more than 80 percent of the lowland hardwood stands were 30 years of age or older. Even though many oak-pine and upland hardwood stands exceed 30 years of age, accumulation of forest biomass is relatively low. The relatively low yield of oak-pine and upland hardwood biomass can be attributed partially to the sparse stocking left on many upland sites after the harvesting of pine stands.

Living Logging Residues

As part of the inventory in Florida, field crews noted at each sample location the primary treatment or disturbance in evidence that had occurred between 1970 and 1980. Bechtold and Knight (1982, table VI) reported the results, by broad management and ownership classes. As part of our evaluation of forest biomass, these acreage estimates were recompiled, eliminating ownership class and redistributing the acreage classed as nonstocked forest among the other broad management classes, based on forest type (table 4).

Some 8 million acres experienced significant treatment or disturbance, and timber harvesting was the most common forestry activity observed. On the average, 257,000 acres were harvested annually, exclusive of intermediate cutting, commercial thinning, and land clearing. Green weight of forest biomass on commercial forest land harvested averaged 16.7 tons per acre (table 5).

For harvesting, thinning, and planting, which occurred during the entire 10-year remeasurement period, one can logically assume that the average biomass measured per acre reflects the quantities some 5 years after the treatment. It is important to keep in mind that broad management classes describe the forest type at the

Table 4.--Area of commercial forest land, by recent past treatment or disturbance, and by broad management class, Florida, 1980

Recent past treatment or disturbance[a]	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Acres					
Harvesting	2,598,731	870,387	556,872	233,009	439,189	499,274
Commercial thinning	387,082	181,797	143,372	10,246	10,571	41,096
Artificial planting	486,812	459,591	--	15,935	0	11,286
Natural disturbance	970,907	245,620	327,928	71,660	108,281	217,418
Other[b]	3,511,096	590,802	1,459,060	339,720	522,006	599,508
None	7,709,549	933,996	2,000,099	753,563	1,053,224	2,968,667
All stands	15,664,177	3,282,193	4,487,331	1,424,133	2,133,271	4,337,249

[a]Primary treatment or disturbance of the stand between 1970 and 1980.

[b]Includes cleaning, release, grazing, draining, prescribed burning, site preparation, and other miscellaneous treatments.

Table 5.--Average green weight of forest biomass per acre of commercial forest land, by recent past treatment or disturbance, and by broad management class, Florida, 1980

Recent past treatment or disturbance[a]	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Tons/Acre					
Harvesting	16.7	4.5	8.6	18.5	19.3	43.9
Commercial thinning	61.2	52.8	62.3	34.7	41.2	106.2
Artificial planting	12.6	12.6	--	7.8	--	20.3
Natural disturbance	52.5	54.2	51.6	52.4	28.8	63.7
Other[b]	55.8	54.6	52.9	50.2	42.0	79.3
None	70.5	45.8	53.4	62.6	49.6	99.3
All stands	55.2	32.8	47.8	51.1	40.4	88.3

[a]Primary treatment or disturbance of the stand between 1970 and 1980.

[b]Includes cleaning, release, grazing, draining, prescribed burning, site preparation, and other miscellaneous treatments.

end of the remeasurement period rather than at the beginning. By broad management class, average weight of forest biomass that was left following harvesting ranged from 4.5 tons per acre in pine plantations to 43.9 tons per acre in lowland hardwood stands. The low average for plantations reflects areas clearcut, site prepared, and planted within the 10-year period. The high average for lowland hardwood reflects quantities of forest biomass left after the high grading of these stands within the same period.

The 16.7 tons of forest biomass per acre shown in table 5 include only material in living trees. Stumps, tops, and limbs of the cut trees left as logging residue are excluded. Even in pine plantations, substantial quantities of these kinds of residue are commonly pushed up into windrows where there is intensive site preparation following harvesting.

Poorly Stocked Stands

Field crews noted obvious opportunities for increasing prospective timber growth on sample plots. Bechtold and Knight (1982, table VII) show acreages providing these management opportunities. For our study, we recompiled the acreage, eliminating ownership class and idle cropland and redistributing nonstocked forest among the other management classes (table 6).

About 5.2 million acres of commercial forest land in Florida were too poorly stocked with acceptable trees to manage for timber production. These acres represent the backlog of needed regeneration on manageable sites in Florida. They contained an average of 28 tons of forest biomass per acre (table 7). The forest biomass on these poorly stocked acres was comprised mostly of rough, rotten, and other low-quality trees. Altogether, these acres contained about 17 percent of the total forest biomass in the State. Practically all of this biomass could be removed and used for energy without adversely affecting prospective timber supplies for the wood-using industries.

Another 93,000 acres supported a manageable stand but will contribute very little net annual growth unless converted to species more suitable to the sites. Such areas contained an average of 34.9 tons of forest biomass per acre.

More than 80,000 acres supported seriously damaged stands that needed to be salvaged and regenerated. These stands contained substantial volume of merchantable timber seriously damaged by fire, insects, disease, wind, ice, or other destructive agents. Forest biomass in these stands averaged 66.5 tons per acre, plus an undetermined amount of wood and bark in dead trees.

Finally, more than 1.4 million acres of immature stands were too densely stocked with small merchantable-size trees or were receiving serious competition from rough trees or other inhibiting vegetation. Without some treatment, growth of these stands will likely be reduced by suppression. Biomass removed during thinning or clearing represents another source of energy wood and would not adversely affect prospective timber supplies.

About 62 percent of the forest biomass in Florida was either in stands in good condition needing no treatment or in stands growing on sites limited by year-round water problems. More than 7.2 million acres supported immature stands in relatively good condition. These stands are at least 60 percent stocked with trees of acceptable quality and free from significant damage or competition. On these acres, forest biomass averaged 58.0 tons per acre. An additional 1.1 million acres supported stands with year-round water problems or slopes of at least 40 percent. On these adverse sites, forest biomass averaged 105 tons per acre. Since 1970, only 15 percent of these sites have experienced any cutting or treatment. Bottom-land hardwood stands accounted for the largest portion of these sites. Such stands probably will not be cut in large quantities at any particular time.

More than 38 percent of the forest biomass in Florida was in stands where prospective energy wood could be har-

Table 6.--Area of commercial forest land, by treatment opportunity class, and by broad management class, Florida, 1980

Treatment opportunity class	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Acres					
Salvage	80,392	19,053	25,975	4,204	--	31,160
Harvest	492,035	--	84,162	35,589	39,545	332,739
Commercial thinning	509,960	242,524	147,627	17,222	3,343	99,244
Other stand improvement	921,651	131,369	222,778	135,948	108,549	323,007
Stand conversion	93,093	7,588	3,061	2,882	46,503	33,059
Regeneration	5,189,956	121,306	1,661,153	719,721	1,477,081	1,210,695
None[a]	7,236,680	2,756,640	2,296,761	444,783	450,376	1,288,120
Adverse sites	1,140,410	3,713	45,814	63,784	7,874	1,019,225
All stands	15,664,177	3,282,193	4,487,331	1,424,133	2,133,271	4,337,249

[a]Immature stands sufficiently stocked with growing-stock trees relatively free from damage or competition.

Table 7.--Average green weight of forest biomass per acre of commercial forest land, by treatment opportunity class, and by broad management class, Florida, 1980

Treatment opportunity class	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
	Tons/Acre					
Salvage	66.5	73.1	57.4	a	--	60.6
Harvest	124.6	--	115.7	126.8	120.6	127.1
Commercial thinning	107.7	85.3	119.5	128.6	a	138.3
Other stand improvement	58.9	40.8	46.0	59.0	59.3	75.2
Stand conversion	34.9	10.6	a	a	31.9	46.4
Regeneration	28.0	7.9	15.6	29.0	27.5	46.9
None[b]	58.0	28.7	63.6	72.7	70.3	101.1
Adverse sites[c]	105.4	a	75.0	64.8	74.8	109.9
All stands	55.2	32.8	47.8	51.1	40.4	88.3

[a]Sample was too small to provide a reliable estimate.

[b]Immature stands adequately stocked with growing-stock trees relatively free from damage or competition.

[c]Areas where harvesting and timber management opportunities are severely limited because of either steep slopes

vested in harmony with conventional forestry practices and opportunities for enhancing future timber growth. A further look at the distribution of forest biomass by tree class, component, and species group provides insight into the amount of forest biomass that could be removed without adversely affecting timber supplies.

Rough and Rotten Trees

Florida's commercial forest land supported 864 million tons of forest biomass in 1980. Growing-stock trees accounted for 82 percent of the forest biomass (table 8). The remaining 18 percent was in trees 1.0-inch d.b.h. and larger which failed to meet minimum standards for growing stock because of species, poor form, or roughness. Theoretically, this biomass could be removed without adversely affecting existing and prospective supplies of timber. About 60 percent of the forest biomass in rough and rotten trees 5.0-inches d.b.h. and larger was in the bole portion. This biomass could be harvested with conventional equipment. The other 40 percent was in saplings, stumps, tops, and limbs and would require specialized harvesting methods.

Other potential sources of forest biomass are stumps, tops, and limbs of growing-stock trees 5.0-inches d.b.h. and larger. Since this material would normally not be available before harvest, the 14 percent of forest biomass in stumps, tops, and limbs of growing-stock trees in table 8 probably overstates the amount of this kind of material at any point in time. From a practical standpoint, the 10 percent forest biomass in growing-stock saplings should not be counted in estimates of energy wood.

Table 8.--Green weight and percent distribution of wood and bark biomass on commercial forest land, by major species group and biomass component, Florida, 1980

Biomass component	All species	Species group				
		Yellow pine	Other softwood	Soft hardwood	Oaks	Other hardwoods
	Percent of green weight					
Growing stock:						
Bole	57.9	71.2	64.6	56.4	40.6	23.9
Stumps, tops, and limbs	13.8	14.3	20.9	13.3	11.7	5.3
Saplings	10.2	13.6	9.1	11.1	4.7	5.0
Total	81.9	99.1	94.6	80.8	57.0	34.2
Rough & rotten:						
Bole	10.8	0.4	2.9	10.1	23.9	46.5
Stumps, tops, and limbs	2.8	0.1	1.5	3.2	8.4	6.3
Saplings	4.5	0.4	1.0	5.9	10.7	13.0
Total	18.1	0.9	5.4	19.2	43.0	65.8
All classes	100.0	100.0	100.0	100.0	100.0	100.0
Green weight (million tons)	863.9	337.2	124.2	178.4	153.0	71.1

Table 8 simplifies the comparison of growing stock and total forest biomass among the major species groups. For example, hardwoods account for less than 36 percent of the total biomass of growing stock but for 47 percent of the total forest biomass.

Totaling Energy Biomass

A few reasonable assumptions are required to estimate the amount of forest biomass that could be harvested for energy in Florida. The 5.2 million acres of poorly stocked timberland classified as offering a regeneration opportunity are the primary source of energy wood that could be harvested without adversely affecting prospective timber supplies. This area supports about 28 tons of forest biomass per acre. If 5 percent of this acreage (259,498 acres) is cleared each year and an average yield of 20 tons per acre is assumed, some 5.2 million tons of energy wood could be harvested annually from these lands over the next 20 years.

The 257,000 acres of timberland harvested annually comprise the next major source of prospective energy wood. We estimate that about 17 tons per acre of forest biomass are left standing after harvest. An earlier study conducted in North Carolina, South Carolina, and Virginia provides an independent estimate of these living residues, expressed in cubic volume of wood (Welch 1980). Welch's volumes convert to roughly 19 tons per acre. If an average of 18 tons per acre is assumed, 4.6 million tons of additional energy wood could be harvested annually from these living residues. Welch also estimated volumes of logging residues for the three South Atlantic States. A conversion of these volumes to weights shows about 16 tons per acre, or another 4.1 million tons statewide, of prospective energy wood each year.

Based on these assumptions, at least 13.9 million tons of energy wood could be harvested annually over the next 20 years in harmony with conventional forestry practices and opportunities, and without adversely affecting timber supplies. On a green weight basis, this tonnage of energy wood is just slightly less than the total harvest of industrial roundwood in Florida in 1979.

Hardwood in Pine Stands

Across the State, Florida's forest biomass on 4.5 million acres of natural pine consisted of 87 percent yellow pine, 11 percent hardwood, and 2 percent other softwoods (table 9). Many pine stands between 15 and 30 years old were established on idle cropland relatively free of hardwood root stocks. Yellow pine accounted for a significantly higher proportion of the biomass in these stands than in pine stands less than 15 years old. Many young pine stands were established on cutover forest land where the hardwood root stocks are entrenched. Even with intensive site preparation for planted pine, hardwoods make up 9 percent of the forest biomass in stands 0-14 years old. In oak-pine stands where pines only account for 25 to 50 percent of the stocking, the pine biomass makes up only 42 percent of the total biomass. Pine makes up only 7 percent of biomass in upland hardwood and 4 percent in lowland hardwood stands. These statistics bear out the region's natural successional trends.

Large Trees in Young Stands

We stated earlier that lowland hardwood stands are keeping pace with the more intensively managed pine plantations in production of total biomass. Table 10 provides some evidence of how this has occurred. More than 60 percent of the total biomass in pine plantations 0-14 years old was in trees less than 5.0 inches d.b.h. Only 31 percent of the trees in young lowland hardwood stands were in the smallest size class. A significant proportion of the biomass in larger trees in the lowland hardwood stands is in larger trees that were left during harvests of former stands. The large trees in the

Table 9.--Percentage distribution of the average green weight of forest biomass per acre of commercial forest land, by species group, by broad management and stand age classes, Florida, 1980

Broad management class and species group	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Percent					
Pine plantation:						
Yellow pines	96	91	96	92	99	--
Other softwoods	--	--	--	--	--	--
Oaks	4	9	4	6	1	--
Other hardwoods	--	--	--	2	--	--
All species	100	100	100	100	100	--
Natural pine:						
Yellow pines	87	76	89	89	87	80
Other softwoods	2	--	2	1	2	6
Oaks	5	19	5	5	5	4
Other hardwoods	6	5	4	5	6	10
All species	100	100	100	100	100	100
Oak-pine:						
Yellow pines	42	44	44	42	43	36
Other softwoods	9	--	5	7	12	12
Oaks	27	45	31	26	22	27
Other hardwoods	22	11	20	25	23	25
All species	100	100	100	100	100	100
Upland hardwood:						
Yellow pines	7	10	8	8	6	3
Other softwoods	--	--	--	--	--	--
Oaks	71	78	75	67	70	73
Other hardwoods	22	12	17	25	24	24
All species	100	100	100	100	100	100
Lowland hardwood:						
Yellow pines	4	8	7	4	3	2
Other softwoods	30	11	20	22	24	38
Oaks	15	24	15	17	16	13
Other hardwoods	51	57	58	57	57	47
All species	100	100	100	100	100	100

Table 10.--Percentage distribution of the average green weight of forest biomass per acre of commercial forest land, by tree diameter class, by broad management and stand age classes, Florida, 1980

Broad management and diameter classes (inches)	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Percent					
Pine plantation:						
1.0-4.9	28	61	23	16	15	--
5.0-8.9	57	32	63	40	53	--
9.0-12.9	12	2	11	37	29	--
13.0+	3	5	3	7	3	--
All classes	100	100	100	100	100	--
Natural pine:						
1.0-4.9	12	32	19	11	8	6
5.0-8.9	27	27	39	28	20	13
9.0-12.9	38	25	33	39	40	38
13.0+	23	16	9	22	32	43
All classes	100	100	100	100	100	100
Oak-pine:						
1.0-4.9	16	36	27	16	13	8
5.0-8.9	23	28	24	27	18	18
9.0-12.9	26	15	25	27	28	26
13.0+	35	21	24	30	41	48
All classes	100	100	100	100	100	100
Upland hardwood:						
1.0-4.9	16	29	28	15	11	6
5.0-8.9	20	27	27	24	19	11
9.0-12.9	21	16	18	26	26	16
13.0+	43	28	27	35	44	67
All classes	100	100	100	100	100	100
Lowland hardwood:						
1.0-4.9	12	31	30	15	11	7
5.0-8.9	21	21	26	26	23	17
9.0-12.9	28	17	22	30	29	28
13.0+	39	31	22	29	37	48
All classes	100	100	100	100	100	100

0-14 age class in natural pine, oak-pine, and upland hardwood stands also are residuals from former stands.

Site and Stocking Affect Yield

Within each management class, we examined the production and distribution of forest biomass in Florida by site, stocking, and age class. The site classes are those used in the timber evaluation. Good sites are those capable of producing 85 cubic feet or more of timber growth per acre annually in fully stocked natural stands; medium sites, 50 to 85 cubic feet; and poor sites, 20 to 50 cubic feet. The stocking classes are based on all live trees rather than growing stock:

Stocking class	Stocked (percent)
Fully stocked	100 or more
Medium stocked	60-100
Poorly stocked	Less than 60

Tables 11-15 show the distribution of acreage within each broad management class by site, stocking, and age class. Statewide, only 45 percent of the commercial forest land was fully stocked. A breakdown of site classes for commercial forest land across the State shows 70 percent of the area to be either good or medium sites. Among the five broad management classes, pine plantations have the highest proportion of good to medium sites. These proportions ranged from a high of 84 percent

Table 11.--Area of commercial forest land supporting pine plantations, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Acres					
Good sites:						
Fully stocked	327,916	100,392	215,970	8,510	3,044	--
Medium stocked	190,183	126,069	58,469	5,645	--	--
Poorly stocked	39,688	26,566	13,122	--	--	--
All stands	557,787	253,027	287,561	14,155	3,044	--
Medium sites:						
Fully stocked	1,125,903	464,319	638,047	20,494	3,043	--
Medium stocked	877,076	494,777	353,349	23,431	5,519	--
Poorly stocked	196,431	124,244	64,909	7,278	--	--
All stands	2,199,410	1,083,340	1,056,305	51,203	8,562	--
Poor sites:						
Fully stocked	277,874	112,397	160,151	5,326	--	--
Medium stocked	172,681	86,129	70,307	10,159	6,086	--
Poorly stocked	74,441	43,874	30,567	--	--	--
All stands	524,996	242,400	261,025	15,485	6,086	--
All sites:						
Fully stocked	1,731,693	677,108	1,014,168	34,330	6,087	--
Medium stocked	1,239,940	706,975	482,125	39,235	11,605	--
Poorly stocked	310,560	194,684	108,598	7,278	--	--
All stands	3,282,193	1,578,767	1,604,891	80,843	17,692	--

Table 12.--Area of commercial forest land supporting natural pine stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Acres					
Good sites:						
Fully stocked	411,061	16,613	103,695	216,124	54,409	20,220
Medium stocked	211,579	3,771	71,196	106,334	23,738	6,540
Poorly stocked	89,622	24,117	20,652	33,597	11,256	--
All stands	712,262	44,501	195,543	356,055	89,403	26,760
Medium sites:						
Fully stocked	693,474	54,325	209,151	257,402	137,371	35,225
Medium stocked	827,403	55,394	289,257	256,345	169,366	57,041
Poorly stocked	830,240	226,454	253,715	199,755	116,385	33,931
All stands	2,351,117	336,173	752,123	713,502	423,122	126,197
Poor sites:						
Fully stocked	223,320	38,866	60,743	68,112	46,588	9,011
Medium stocked	441,397	33,835	98,718	106,873	155,039	46,932
Poorly stocked	759,235	78,425	247,687	206,252	145,564	81,307
All stands	1,423,952	151,126	407,148	381,237	347,191	137,250
All sites:						
Fully stocked	1,327,855	109,804	373,589	541,638	238,368	64,456
Medium stocked	1,480,379	93,000	459,171	469,552	348,143	110,513
Poorly stocked	1,679,097	328,996	522,054	439,604	273,205	115,238
All stands	4,487,331	531,800	1,354,814	1,450,794	859,716	290,207

for pine plantations to a low of 51 percent for upland hardwood stands. On the other hand, the lowland hardwood management class had the highest proportion of fully stocked stands. These proportions ranged from a high of 66 percent for lowland hardwood to a low of 28 percent for upland hardwood stands. The low averages for upland hardwood stands reflect both a large acreage of scrub oak included in this management class and inadequate regeneration efforts after harvest.

Table 13.--Area of commercial forest land supporting oak-pine stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Acres					
Good sites:						
Fully stocked	129,030	23,594	14,137	47,736	23,524	20,039
Medium stocked	93,864	14,319	7,032	40,940	25,050	6,523
Poorly stocked	24,069	9,741	3,907	10,421	--	--
All stands	246,963	47,654	25,076	99,097	48,574	26,562
Medium sites:						
Fully stocked	302,682	50,570	75,221	88,940	48,676	39,275
Medium stocked	230,233	23,587	71,886	63,404	55,120	16,236
Poorly stocked	145,490	41,879	43,870	40,918	12,058	6,765
All stands	678,405	116,036	190,977	193,262	115,854	62,276
Poor sites:						
Fully stocked	133,287	17,383	25,372	45,720	25,960	18,852
Medium stocked	214,748	26,489	43,691	56,499	57,628	30,441
Poorly stocked	150,730	39,699	28,049	44,792	22,486	15,704
All stands	498,765	83,571	97,112	147,011	106,074	64,997
All sites:						
Fully stocked	564,999	91,547	114,730	182,396	98,160	78,166
Medium stocked	538,845	64,395	122,609	160,843	137,798	53,200
Poorly stocked	320,289	91,319	75,826	96,131	34,544	22,469
All stands	1,424,133	247,261	313,165	439,370	270,502	153,835

Table 14.--Area of commercial forest land supporting upland hardwood stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Acres					
Good sites:						
Fully stocked	80,608	14,903	12,906	32,035	13,701	7,063
Medium stocked	78,367	7,876	6,861	22,548	22,605	18,477
Poorly stocked	31,555	19,031	8,754	3,770	--	--
All stands	190,530	41,810	28,521	58,353	36,306	25,540
Medium sites:						
Fully stocked	323,103	85,271	76,915	62,892	46,032	51,993
Medium stocked	415,269	61,206	71,391	135,099	75,567	72,006
Poorly stocked	161,819	91,729	18,774	23,562	16,660	11,094
All stands	900,191	238,206	167,080	221,553	138,259	135,093
Poor sites:						
Fully stocked	189,710	44,704	40,262	61,888	27,587	15,269
Medium stocked	444,216	90,780	93,019	161,202	67,371	31,844
Poorly stocked	408,624	157,482	97,309	73,779	59,063	20,991
All stands	1,042,550	292,966	230,590	296,869	154,021	68,104
All sites:						
Fully stocked	593,421	144,878	130,083	156,815	87,320	74,325
Medium stocked	937,852	159,862	171,271	318,849	165,543	122,327
Poorly stocked	601,998	268,242	124,837	101,111	75,723	32,085
All stands	2,133,271	572,982	426,191	576,775	328,586	228,737

Table 15.--Area of commercial forest land supporting lowland hardwood stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Acres					
Good sites:						
Fully stocked	275,009	44,886	18,682	63,695	80,942	66,804
Medium stocked	88,703	7,176	22,371	12,280	26,613	20,263
Poorly stocked	25,756	3,326	15,435	6,995	--	--
All stands	389,468	55,388	56,488	82,970	107,555	87,067
Medium sites:						
Fully stocked	1,889,957	86,920	150,290	396,526	557,891	698,330
Medium stocked	664,283	43,724	101,891	209,752	165,552	143,364
Poorly stocked	202,899	45,599	44,110	51,806	34,006	27,378
All stands	2,757,139	176,243	296,291	658,084	757,449	869,072
Poor sites:						
Fully stocked	692,301	23,871	69,052	139,311	155,106	304,961
Medium stocked	320,307	30,136	56,880	93,640	65,923	73,728
Poorly stocked	178,034	49,736	43,943	38,333	30,768	15,254
All stands	1,190,642	103,743	169,875	271,284	251,797	393,943
All sites:						
Fully stocked	2,857,267	155,677	238,024	599,532	793,939	1,070,095
Medium stocked	1,073,293	81,036	181,142	315,672	258,088	237,355
Poorly stocked	406,689	98,661	103,488	97,134	64,774	42,632
All stands	4,337,249	335,374	522,654	1,012,338	1,116,801	1,350,082

Tables 16-20 show the average green weight of forest biomass per acre within each broad management class by site, stocking, and age class. Since more than 97 percent of pine plantations were less than 30 years old, the relatively low value of 33 tons per acre for the 3.3 million acres of planted pine is not surprising (table 16). The number of sample plantations established before the Soil Bank era was too small to estimate yields for the 30-44 age class. Even with this void in the data, it is safe to assume that fully stocked good sites will yield 100 tons of biomass per acre in 30 years. Across all age classes, fully stocked pine plantations on good sites produced about 12 times more biomass than poorly stocked plantations on poor sites.

The 4.5 million acres of natural pine contained an average of 48 tons of biomass per acre (table 17). Fully stocked natural pine stands on good sites produced more than 100 tons of biomass per acre in 30 years. For all age classes, fully stocked natural pine stands on good sites produced about eight times more biomass than the poorly stocked stands on poor sites.

The average biomass on the 1.4 million acres of oak-pine was 51 tons per acre (table 18). Many of these stands are on sites from which pines were harvested but not adequately regenerated. Biomass yield data presented in table 18 reveal that fully stocked stands on good sites can achieve 100 tons per acre in 30 years. For all age classes, fully stocked oak-pine stands on good sites produced

about seven times more biomass than the poorly stocked stands on poor sites.

Upland hardwoods occupied more than 2.1 million acres. Like oak-pine, many of these stands are on sites that previously supported pine. Even though a large percentage of upland hardwood stands exceeds 30 years of age, forest biomass values are relatively low. In all upland hardwood stands combined, biomass averaged 40 tons per acre (table 19). This low production of biomass is directly related to sparse stocking on many upland sites. Results show, however, that fully stocked upland hardwood stands on good sites will produce 100 tons of biomass per acre in 30 years. For all upland hardwood age classes, fully stocked stands on good sites produce more than 10 times more biomass than the poorly stocked stands on poor sites.

Finally, the 4.3 million acres classed as lowland hardwood contain more than 88 tons per acre (table 20). This management class alone makes up 44 percent of Florida's forest biomass. The high weight is attributed to the large proportion (80 percent) of lowland hardwood stands that are 30 years of age or older. Also, more than two-thirds of the stands were fully stocked. Fully stocked lowland hardwood stands on good sites yield 100 tons of biomass per acre in 30 years. For all age classes combined, fully stocked stands on good sites contained about 14 times more biomass than the poorly stocked stands on poor sites.

Table 16.--Average green weight of forest biomass per acre of commercial forest land supporting pine plantations, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Good sites:						
Fully stocked	67.6	15.9	90.1	a	a	--
Medium stocked	25.5	10.3	50.7	a	--	--
Poorly stocked	12.6	4.8	28.3	--	--	--
All stands	49.4	12.0	79.3	a	a	--
Medium sites:						
Fully stocked	44.3	15.2	64.2	77.9	a	--
Medium stocked	21.9	8.4	38.3	51.9	a	--
Poorly stocked	10.8	3.7	21.9	a	--	--
All stands	32.4	10.8	52.9	59.8	a	--
Poor sites:						
Fully stocked	21.1	5.8	28.9	a	--	--
Medium stocked	15.2	4.2	20.7	a	a	--
Poorly stocked	5.6	3.0	9.4	--	--	--
All stands	16.9	4.7	24.4	a	a	--
All sites:						
Fully stocked	45.0	13.7	64.1	85.8	a	--
Medium stocked	21.5	8.3	37.3	58.6	a	--
Poorly stocked	9.8	3.7	19.1	a	--	--
All stands	32.8	10.0	53.0	68.0	a	--

[a]Sample was too small to provide a reliable estimate.

Table 17.--Average green weight of forest biomass per acre of commercial forest land supporting natural pine stands, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Good sites:						
Fully stocked	115.5	33.0	102.4	115.8	139.5	181.5
Medium stocked	66.1	a	48.5	72.9	93.2	a
Poorly stocked	30.0	1.4	25.4	38.6	74.0	--
All stands	90.1	13.8	74.7	95.7	118.9	157.3
Medium sites:						
Fully stocked	85.0	20.4	66.9	88.5	113.9	154.1
Medium stocked	51.8	11.9	37.0	58.4	74.8	67.4
Poorly stocked	15.4	0.6	11.5	23.8	30.0	42.7
All stands	48.7	5.7	36.7	59.6	75.2	85.0
Poor sites:						
Fully stocked	45.2	11.5	43.1	45.3	69.2	79.4
Medium stocked	36.5	6.7	20.7	40.2	42.1	63.8
Poorly stocked	12.9	1.8	9.5	11.8	18.7	26.3
All stands	25.3	5.4	17.2	25.7	36.0	42.6
All sites:						
Fully stocked	87.7	19.2	72.9	94.0	111.0	152.2
Medium stocked	49.3	9.8	35.3	57.6	61.5	66.7
Poorly stocked	15.0	1.0	11.1	19.3	25.8	31.1
All stands	47.8	6.3	36.3	59.6	63.9	71.6

[a]Sample was too small to provide a reliable estimate.

Table 18.--Average green weight of forest biomass per acre of commercial forest land supporting oak-pine stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Good sites:						
Fully stocked	105.3	15.8	101.2	127.4	125.7	137.0
Medium stocked	66.4	a	a	72.9	91.3	a
Poorly stocked	a	a	a	a	--	--
All stands	82.8	9.7	72.9	96.9	107.9	124.5
Medium sites:						
Fully stocked	82.4	15.6	55.5	94.4	128.6	135.3
Medium stocked	50.1	17.4	40.8	56.5	64.4	65.2
Poorly stocked	13.9	3.3	13.4	21.1	30.3	a
All stands	56.7	11.5	40.3	66.4	87.8	103.4
Poor sites:						
Fully stocked	40.6	15.0	30.0	43.5	37.2	75.8
Medium stocked	28.2	21.1	24.3	28.9	32.9	29.3
Poorly stocked	15.6	10.0	17.6	17.8	16.0	19.3
All stands	27.7	14.6	23.9	30.1	30.4	40.4
All sites:						
Fully stocked	77.7	15.6	55.5	90.3	103.7	121.4
Medium stocked	44.2	16.0	35.3	51.0	56.1	47.2
Poorly stocked	15.6	6.1	15.1	22.9	21.0	16.5
All stands	51.1	12.2	37.8	61.2	68.9	80.4

[a]Sample was too small to provide a reliable estimate.

Table 19.--Average green weight of forest biomass per acre of commercial forest land supporting upland hardwood stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Good sites:						
Fully stocked	101.3	35.5	94.2	105.1	150.1	a
Medium stocked	74.0	a	a	70.0	93.2	101.6
Poorly stocked	12.7	1.7	a	a	--	--
All stands	75.4	16.5	51.8	88.4	114.6	112.7
Medium sites:						
Fully stocked	66.8	21.4	49.0	82.9	95.8	122.4
Medium stocked	57.2	19.0	46.7	51.9	72.8	94.0
Poorly stocked	18.5	3.4	17.1	36.3	48.5	63.4
All stands	53.7	13.9	44.4	59.0	77.5	102.4
Poor sites:						
Fully stocked	35.1	20.8	25.7	33.7	51.9	77.5
Medium stocked	28.7	18.9	23.3	24.7	46.6	55.1
Poorly stocked	9.8	5.6	8.0	12.5	17.7	18.9
All stands	22.5	12.1	17.2	23.5	36.5	49.0
All sites:						
Fully stocked	61.4	22.7	46.3	68.0	90.4	115.0
Medium stocked	45.1	18.8	32.7	39.4	64.9	85.0
Poorly stocked	12.3	4.6	10.0	19.7	24.5	34.3
All stands	40.4	13.1	30.2	43.7	62.4	87.6

[a]Sample was too small to provide a reliable estimate.

Table 20.--Average green weight of forest biomass per acre of commercial forest land supporting lowland hardwood stands, by site, stocking, and stand age classes, Florida, 1980

Site and stocking classes	All age classes	Stand age class (years)				
		0-14	15-29	30-44	45-59	60+
	Tons/Acre					
Good sites:						
Fully stocked	119.0	33.2	83.0	116.8	134.9	169.4
Medium stocked	66.7	a	53.1	47.6	68.3	112.4
Poorly stocked	12.1	a	6.4	a	--	--
All stands	100.0	28.0	50.2	99.1	118.4	156.1
Medium sites:						
Fully stocked	119.5	25.7	68.1	102.9	114.8	155.4
Medium stocked	57.3	22.7	43.3	49.4	61.9	84.2
Poorly stocked	15.6	1.6	5.5	20.4	29.5	28.8
All stands	96.9	18.7	50.2	79.3	99.4	139.7
Poor sites:						
Fully stocked	91.1	19.9	57.7	78.0	93.6	108.9
Medium stocked	37.9	19.4	26.5	34.8	47.7	49.3
Poorly stocked	8.7	1.1	6.0	8.5	11.0	37.6
All stands	64.4	10.7	33.9	53.2	71.5	95.0
All sites:						
Fully stocked	112.6	27.0	66.2	98.6	112.7	143.1
Medium stocked	52.3	20.1	39.2	45.0	59.0	75.8
Poorly stocked	12.4	1.4	5.8	16.3	20.7	31.9
All stands	88.3	17.8	44.9	74.0	94.9	127.7

[a]Sample was too small to provide a reliable estimate.

CONCLUSIONS

Several conclusions can be drawn bout the quantity, composition, distribution, and prospective availability f forest biomass on commercial forest and in Florida in 1980:

- Florida's 15.7 million acres of imberland supported 864 million tons f forest biomass, or an average of 5.2 tons per acre. This quantity exeeded the green weight of conventional rowing stock by 73 percent.
- Conventional growing stock accuulates somewhat faster in pine stands, specially in pine plantations, than in ak-pine and hardwood stands. By broad anagement class, across all age classs, average weight of conventional rowing stock ranged from a low of 17.0 ons per acre in upland hardwood to a igh of 48.7 tons per acre in lowland ardwood stands.
- On the average, about 257,000 cres of timberland are harvested annuly in Florida and retained in commerial forest. This average excludes ommercial thinning, other intermediate utting, and land clearing. Forest iomass left in standing trees after arvest averaged approximately 17 tons er acre. From an earlier study, an stimated additional 16 tons per acre n stumps, tops, and limbs of the cut rees are left as logging residues. rospectively, these living and logging residuals are primary sources of nergy wood.
- About 5.2 million acres of comercial forest land were too poorly tocked with acceptable trees for timer production unless regenerated. hese acres supported an average of 28 ons per acre of forest biomass mostly omprising rough, rotten, and other ow-quality trees with a scattering of growing stock intermingled among them. Altogether, these acres supported about 17 percent of the total forest biomass. Most of this biomass could be removed and used for energy without adversely affecting prospective timber supplies.
- More than 38 percent of the forest biomass was in stands where prospective energy wood could be harvested in harmony with conventional forestry practices and opportunities for enhancing future timber growth. The remaining 62 percent was either in stands exhibiting no obvious treatment opportunity or on sites where water severely limits harvesting and management.
- Almost 8 percent of the forest biomass was in rough and rotten trees and could be removed without adversely affecting existing or prospective supplies of sawtimber. About 60 percent of the forest biomass in rough and rotten trees was in boles of trees 5.0 inches d.b.h. and larger. The other 40 percent was in saplings, stumps, tops, and limbs.
- When a few reasonable assumptions are superimposed onto these findings, an estimate of at least 13.9 million tons of forest biomass could be harvested annually in Florida over the next 2 decades without adversely affecting timber supplies. The green weight of this energy wood is slightly less than the total green weight of the harvest of industrial roundwood in Florida in 1979.
- For all management classes, fully stocked stands on good sites yield 10 times more forest biomass than the poorly stocked stands on poor sites. Regardless of the management class, fully stocked stands on good sites can yield 100 tons of biomass per acre in 30 years.

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Multiresource inventories: forest biomass in Florida. Res. Pap. SE-235. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1982. 24 p.

Florida's 15.7 million acres of timberland support 864 million tons of forest biomass, or an average of 55.2 tons per acre. This total exceeds the green weight of conventional growing stock by 73 percent. More than 38 percent of the total forest biomass is in stands where wood could be harvested for energy in harmony with conventional forestry practices. Over the next 2 decades, about 14.0 million tons of forest biomass could be harvested annually without adversely affecting timber supplies.

KEYWORDS: Growing stock, commercial forest land, multiple use.

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The Hardwood Resource on Nonindustrial Private Forest Land in the Southeast Piedmont

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1983
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The Hardwood Resource on Nonindustrial Private Forest Land in the Southeast Piedmont

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Abstract

More than half of the commercial forest land in the Southeast Piedmont supports hardwood stands held by small nonindustrial private landowners. Total biomass production would increase 15 to 20 percent if these stands were fully stocked, and much of the present production could be shifted to more desirable species. Only 21 percent of all nonindustrial private forest (NIPF) stands are fully stocked with growing-stock trees.

Piedmont hardwood stands contain an average of 75.5 tons per acre of aboveground tree biomass. When these stands are harvested, 39.1 tons of living residues are left behind in the form of rough or rotten cull trees and noncommercial saplings. It is this practice which has caused the large number of poor-quality stands we have today. If the timber remaining after harvest is not marketable, it should be felled to encourage the natural regeneration of more desirable species.

Only 37 percent of all hardwood biomass harvested (standing and felled) is currently being utilized. The product output from the hardwood resource could at least be doubled with no threat to conventional hardwood supplies by improving utilization. Dramatic increases in hardwood production can be expected if NIPF owners can be persuaded to employ relatively inexpensive management techniques.

Keywords: Nonindustrial private forest land, forest trends, hardwood forest land, Piedmont forest land, forest biomass, hardwood timber volume, hardwood silviculture.

Introduction

Biological, economic, and social forces occurring between 1945 and 1965 led to the establishment of much of the vast southern pine resource we know today (Boyce and Knight 1979). Forest industry has provided the capital and technology needed to use the pine resource, and forest managers have devoted their efforts to its maintenance and improvement. Because of the numerous advantages associated with pines, hardwood management has been discouraged for decades. Long rotations, low stumpage values, expensive cultural treatments, and the absence of dependable hardwood markets have limited options available to those willing to improve the quality of their hardwood stands (Sosbe 1966). A common management approach has been to eradicate and convert hardwood stands to pine (Kellison 1971). Despite decades of such obstruction, hardwoods have been gaining ground on southern pines for at least 10 years and are likely to continue to do so. Current biological, social, and economic forces favoring hardwoods outweigh the cultural practices that favor pine (Boyce and Knight 1980).

The front line of this hardwood advance is on nonindustrial private forest (NIPF) land. For a variety of reasons, many NIPF owners have opted against the intensive cultural treatments required to regenerate pine after harvest. Many NIPF owners cannot profitably employ expensive industrial management techniques, or do not share the same management objectives as forest industry (Kingsley 1980). Oftentimes landowners are simply willing to accept whatever nature offers, and low-quality hardwood stands are permitted to develop by default. This passive or "custodial" approach to forest management is becoming increasingly costly to NIPF owners in terms of lost opportunities. Many can profitably improve their hardwood stands and still satisfy their nontimber needs.

The marginal productivity of NIPF hardwood stands is partially attributable to unfavorable market conditions but, as pine supplies decline, hardwoods can be used to supplement or replace pine in many products. Soft-textured hardwood species are being peeled into veneer for the inner plies of southern pine plywood. Hardwoods are also being substituted for pine in board products, in paper, and in some solid-wood products.

As opportunities to use low-quality hardwoods materialize, management options available to the NIPF owner will expand accordingly. Improved hardwood management guidelines are needed to help the small landowner grow more and better timber while meeting needs for firewood, good wildlife habitat, and esthetic values.

This paper describes the status of the NIPF hardwood resource in the Piedmont of the Southeast. It identifies areas with potential for major improvement, outlines a few inexpensive management practices the NIPF owner might adopt to make improvements, and provides a database for continuing hardwood research in the area.

Procedures

The Southeast Piedmont ranges from North Carolina to Georgia and encompasses 44 million acres.[1/] The Piedmont boundaries delineated in figure 1 follow Survey Unit boundaries used by the USDA Forest Service for statewide multiresource inventories. Data collected during the latest inventories of these six Units over a 5-year period were pooled for presentation in this report. Additional information and inventory procedures are outlined in the latest Resource Bulletins for the Piedmo Units of each State: Central and North Central Georgia (Cathey 1972; Knight 1972), the Piedmont of North Carolina (Welch 1975), the Southern and Northern Piedmont of Virginia (Sheffield 1976, 1977), and the Piedmont of South Carolin (Snyder 1978).

Initial estimates of forest and nonforest land area were based on the classification of 150,947 16-point sample clusters systematically spaced on the latest aerial photographs available. To adjust for changes since photos were tak and for errors in photo interpretation, 10,693 of these clusters were then examined on the ground.

Estimates of timber volumes and forest classifications were based on measuremen recorded at 6,573 ground sample location systematically distributed on commercial forest land. At each sample location, trees 5.0 inches d.b.h. and larger were selected for measurement at 3 to 10 poin with a basal area factor of 37.5 square feet per acre. Trees less than 5.0 inch d.b.h. were tallied on fixed radius plot around the point centers.

Plot tallies were converted to volumes through a series of volume prediction equations derived from detailed measurements of over 35,000 trees throughout th Southeast (Cost 1978). Area statistics were then used to expand the per-acre volumes measured on the sample plots to volume estimates for the entire study area.

The utilization of hardwood removals w determined by merging information from several sources. Primary wood-using mil were canvassed to obtain information on wood receipts destined for industrial pr ucts. Timber volume removed for fuel, removed due to cultural operations and land clearing, and volume left standing

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[1/] Includes 389,000 acres of water according to Survey standards of area classification but defined by the Bureau of Census as land.

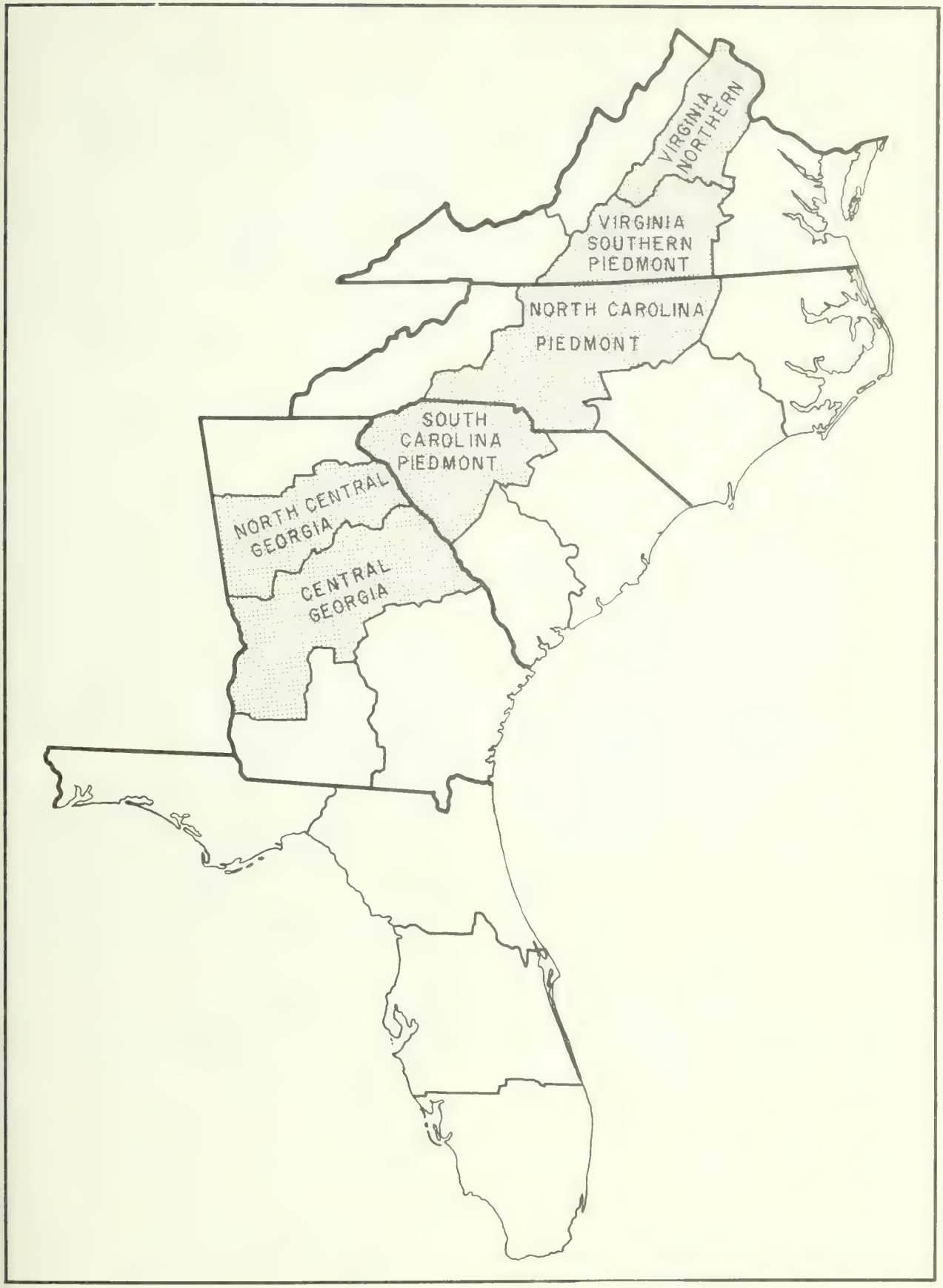

Figure 1.--Forest survey units in the Southeast Piedmont.

areas where classification changed from commercial forest to nonforest were estimated from the permanent remeasurement samples. Felled trees were measured at a sample of active harvesting operations to develop a measure of logging residues. Results of an earlier study, also based on the remeasurement of permanent samples and active cutting operations, were used to estimate volume in residual trees (living residues) left on commercial forest following harvest (Welch 1980).

Biomass, as used in this paper, is defined as the aboveground green weight of wood and bark in all live trees 1.0 inch d.b.h. and larger, including limbs greater than 0.5 inches at the base, but excluding all foliage. Tree volumes were converted to weight with equations developed by the Utilization of Southern Timber Research Unit of the Southeastern Forest Experiment Station in Athens, Georgia (Saucier 1979).

Included with the hardwood forest types referred to in this paper is the oak-pine type. This type generally results from harvesting pine stands and leaving a residual of nonmerchantable hardwoods and pines. In this class, pines make up at least 25 percent of the stocking, but not more than 50. Oak-pine figures for Georgia may be slightly distorted because sample plots were allowed to straddle two or more conditions. If one portion of the plot was in an oak-hickory stand and the other in a pine stand, the area was often typed as oak-pine. Since the last Georgia survey, straddling has been eliminated.

The NIPF Hardwood Perspective

More than 28 million acres, or some 64 percent of the total land area in the Southeast Piedmont, are classified as commercial forest. Of these 28 million acres, one-half support hardwood stands held by nonindustrial private owners. Although this assessment is largely confined to the forest biomass on these 14 million acres, it is important to understand the relationship of NIPF hardwood stands to all other stands in the Piedmont. Tables 1-3 provide the breakdown of the total Piedmont timberland acreage and associated biomass by State, ownership, and broad management class.

About 17 million acres, or 59 percent of the Piedmont commercial forest acreage, is allocated among the three hardwood types: oak-pine, upland hardwood, and lowland hardwood (table 1). The remaining acres are in pine forest types, 16 percent of which have been planted. Moving through the Piedmont from north to south, the proportion of total timberland acreage in hardwood types decreases from a high of 71 percent in Virginia to a low of 50 percent in South Carolina and Georgia.

NIPF owners possess over 23 million acres, or 82 percent of the Piedmont commercial forest. They own 94 percent of the Piedmont timberland in North Carolina, 83 percent in Virginia, 78 percent in Georgia, and 77 percent in South Carolina.

The distribution of biomass throughout the Piedmont is similar to the allocation of acreage (table 2). Nearly 1.3 billion tons, or 62 percent of the total Piedmont biomass, occurs in the hardwood classes. Planted pine accounts for only 4 percent of all Piedmont forest biomass. As with acreage, the relative amount of biomass in hardwood forest types decreases from north to south. NIPF landowners own 1.7 billion tons, or 83 percent of the total biomass in the Piedmont. Their portion ranges from 93 percent of the biomass in the North Carolina Piedmont to 77 percent in South Carolina and Georgia.

Nearly 53 percent of the total forest biomass in the Southeast Piedmont occurs within NIPF hardwood stands. NIPF upland hardwood stands by themselves contain over one-third of the total Piedmont biomass. NIPF oak-pine stands, which are very similar to upland hardwood stands, account for another 12 percent. Only 6 percent of the total Piedmont biomass is in NIPF lowland hardwood stands.

Tons of biomass per acre in NIPF stands are very close to State averages because these averages are heavily weighted by large numbers of NIPF acres (table 3). More biomass per acre is on public land because stands there are generally older than NIPF stands. Conversely, less biomass has accumulated on forest industry land because its stands are younger and have shorter rotations. The same logic holds when examining the broad forest types. Lowland hardwood stands have accumulated

Table 1.--Area of commercial forest land by State, year, ownership group, and broad forest type, Southeast Piedmont

State and year	Ownership group[a]	Broad forest type					
		All classes	Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
		Thousand acres					
Georgia 1972	Public	449.0	28.7	247.0	79.0	64.5	29.8
	Forest industry	1,995.6	352.2	741.8	308.5	390.4	202.7
	Other private	8,876.4	619.5	3,620.7	1,616.3	2,106.5	913.4
Total		11,321.0	1,000.4	4,609.5	2,003.8	2,561.4	1,145.9
South Carolina 1977	Public	428.8	20.0	235.8	50.9	107.9	14.2
	Forest industry	628.2	192.9	195.2	59.5	153.4	27.2
	Other private	3,471.1	193.1	1,419.0	563.2	1,208.7	87.1
Total		4,528.1	406.0	1,850.0	673.6	1,470.0	128.5
North Carolina 1975	Public	143.3	.5	40.6	27.1	41.9	33.2
	Forest industry	237.2	58.1	57.7	42.8	74.4	4.2
	Other private	5,647.5	111.7	1,827.3	757.5	2,572.3	378.7
Total		6,028.0	170.3	1,925.6	827.4	2,688.6	416.1
Virginia 1976	Public	306.4	.6	69.5	30.5	202.2	3.6
	Forest industry	781.7	158.7	168.5	107.3	317.5	29.7
	Other private	5,242.4	148.5	1,094.9	569.1	3,232.1	197.8
Total		6,330.5	307.8	1,332.9	706.9	3,751.8	231.1
All States	Public	1,327.5	49.8	592.9	187.5	416.5	80.8
	Forest industry	3,642.7	761.9	1,163.2	518.1	935.7	263.8
	Other private	23,237.4	1,072.8	7,961.9	3,506.1	9,119.6	1,577.0
Total		28,207.6	1,884.5	9,718.0	4,211.7	10,471.8	1,921.6

[a]Forest industry figures include 337.9 thousand acres of commercial forest land leased from NIPF owners.

Table 2.--Total green weight of aboveground biomass (excluding foliage) by State, year, ownership group, and broad forest type, Southeast Piedmont

State and year	Ownership group[a]	Broad forest type					
		All classes	Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
		Million tons					
Georgia 1972	Public	37.1	1.7	22.5	5.8	3.8	3.3
	Forest industry	124.5	12.8	50.4	17.2	22.7	21.4
	Other private	554.1	27.3	215.3	100.9	135.6	75.0
Total		715.7	41.8	288.2	123.9	162.1	99.7
South Carolina 1977	Public	45.7	.7	24.8	3.7	13.7	2.8
	Forest industry	33.9	7.7	14.3	2.2	6.5	3.2
	Other private	273.4	14.6	106.0	42.0	102.5	8.3
Total		353.0	23.0	145.1	47.9	122.7	14.3
North Carolina 1975	Public	14.4	--	5.2	3.1	3.3	2.8
	Forest industry	18.9	1.0	6.6	4.0	6.6	.7
	Other private	445.9	8.3	143.1	57.3	205.4	31.8
Total		479.2	9.3	154.9	64.4	215.3	35.3
Virginia 1976	Public	31.2	--	6.4	2.4	21.8	.6
	Forest industry	49.2	4.3	11.4	5.4	25.9	2.2
	Other private	402.6	4.7	84.4	39.8	260.2	13.5
Total		483.0	9.0	102.2	47.6	307.9	16.3
All States	Public	128.4	2.4	58.9	15.0	42.6	9.5
	Forest industry	226.5	25.8	82.7	28.8	61.7	27.5
	Other private	1,676.0	54.9	548.8	240.0	703.7	128.6
Total		2,030.9	83.1	690.4	283.8	808.0	165.6

[a]Forest industry figures include 14.4 million tons of biomass on commercial forest land leased from NIPF owners.

Table 3.--Average green weight of aboveground biomass (excluding foliage) per acre by State, year, ownership group, and broad forest type, Southeast Piedmont

State and year	Ownership group[a]	Broad forest type					
		All classes	Pine plantation	Natural pine	Oak-pine	Upland hardwood	Lowland hardwood
		Tons per acre					
Georgia 1972	Public	82.6	58.9	90.9	73.7	59.2	110.2
	Forest industry	62.4	36.4	67.9	55.8	58.0	105.7
	Other private	62.4	44.0	59.5	62.4	64.4	82.1
	All owners	63.2	41.8	62.5	61.9	63.3	87.0
South Carolina 1977	Public	106.7	37.4	105.0	72.0	127.5	197.5
	Forest industry	53.9	40.1	73.4	35.8	42.6	115.6
	Other private	78.8	75.9	74.6	74.5	84.8	95.1
	All owners	78.0	57.0	78.4	70.9	83.6	110.7
North Carolina 1975	Public	100.5	--	129.2	114.7	78.9	82.4
	Forest industry	79.6	16.7	113.9	94.1	88.0	180.1
	Other private	79.0	74.1	78.3	75.6	79.9	84.0
	All owners	79.5	54.3	80.5	77.8	80.1	84.9
Virginia 1976	Public	102.0	--	92.8	78.9	107.6	172.9
	Forest industry	63.0	26.9	67.8	50.1	81.7	74.5
	Other private	76.8	31.6	77.1	69.9	80.5	68.4
	All owners	76.3	29.1	76.7	67.3	82.1	70.8
All States	Public	96.8	49.0	99.4	80.0	102.4	116.9
	Forest industry	62.2	33.8	71.1	55.5	65.9	104.4
	Other private	72.1	51.2	68.9	68.4	77.2	81.6
	All owners	72.0	44.1	71.0	67.4	77.2	86.2

[a]Forest industry figures include lands leased from NIPF owners.

high average amounts of biomass due to long rotations, while pine plantations are younger and have accumulated significantly less biomass.

NIPF Hardwood Stand Composition

Quality, species, and size distribution of the 1.1 billion tons of forest biomass in NIPF hardwood stands are given in tables 4 and 5. Totals shown include 147 million tons of biomass in softwood species in these hardwood stands. Not included are 120 million tons of hardwood biomass occurring in NIPF pine stands. In NIPF hardwood stands, total green weight of all forest biomass exceeds the weight of conventional growing stock by 66 percent. Only 60 percent of total biomass is in the bole portion of growing-stock trees; 14 percent is in the stumps and tops of growing-stock trees, 11 percent in rough or rotten trees, and 15 percent in saplings. These averages do not vary significantly by State.

On the average, oak-pine stands tend to have a lower proportion of biomass in rough and rotten timber than do pure hardwood stands. Since oak-pine stands have usually been more heavily cut, and thus more open than the two other hardwood types, they have a higher proportion of biomass in saplings. Lowland hardwood stands have the highest percentage of biomass in rough and rotten trees, because these stands are generally older and receive less treatment than upland stands.

Oaks account for more forest biomass than any other species group (table 5). At 126 million tons, more biomass has collected in white oak than any other single species. White oak, yellow-poplar, sweetgum, and hickory together account for more than one-third of the total tree biomass in NIPF Piedmont hardwood stands.

Nearly two-thirds of the biomass in these stands is concentrated in trees between 5 and 15 inches in diameter, and the greatest accumulation is in the 10-inch class. One-half of the total green weight of forest biomass is in sawtimber-size trees, 35 percent in poletimber, and the remainder in saplings.

Hardwood Stand Performance

Two variables important to the performance of all timber stands are stocking and site quality. In this analysis we demonstrate the effects that varying degrees of site and stocking have on the performance of NIPF hardwood stands. Oak-pine, upland hardwood, and lowland hardwood stands were grouped because no significant differences were observed when these stands were examined separately. Georgia data were omitted because stand age information collected during the fourth survey of Georgia was weakened by plots straddling more than one condition and the grouping of some stands into mixed age classes. We assume hardwood stands in Georgia perform similarly to those in the rest of the Piedmont.

Stocking levels are based on all live trees, and stocking standards are defined in table 6. Stands 100 percent or more stocked are fully stocked; stands 60 to 99 percent stocked are medium stocked; and stands less than 60 percent stocked are poorly stocked.

Site class is a measure of the inherent capacity of land to grow crops of industrial wood based in fully stocked natural stands. Sites capable of producing more than 85 cubic feet (roughly 3 tons) of wood per acre per year are good sites. Sites able to produce 50 to 85 cubic feet per acre annually are medium sites, and sites capable of producing only 20 to 50 cubic feet are poor sites.

Figures 2 and 3 isolate the effects of stocking on stand performance. These graphs represent the net results of all past treatments and disturbances, and therefore show how NIPF Piedmont hardwood stands are performing collectively. Care is advised in the interpretation of these figures, because a particular stand may not necessarily follow the delineated performance patterns throughout its entire lifespan. Depending on what treatments or disturbances a stand experiences, it could easily jump from one stocking level to another during its development. Indeed, there is a tendency for both fully stocked and poorly stocked stands to drift toward medium stocking as they get older.

Figure 2 shows how biomass accumulates over time. Stands are grouped into 10-year age classes, and the average biomass is plotted at each age-class midpoint. By age 30, stands at each stocking level have accumulated well over half of the biomass they are likely to accumulate if allowed to proceed to age 100. Across

Table 4.--Total green weight of aboveground biomass (excluding foliage) on NIPF hardwood stands in the Southeast Piedmont by State, year, hardwood broad forest type, and tree component[a]

State and year	Broad forest type	Aboveground biomass			Trees 5.0 inches d.b.h. and larger						Saplings total
					Growing stock			Rough and rotten			
		Total	Bole	Other[b]	Total	Bole	Other	Total	Bole	Other	
		Million tons									
Georgia 1972	Oak-pine	100.9	66.3	34.6	74.3	60.7	13.6	7.5	5.6	1.9	19.1
	Upland hardwood	135.6	89.1	46.5	95.6	77.0	18.6	16.3	12.1	4.2	23.7
	Lowland hardwood	75.0	52.8	22.2	55.8	45.7	10.1	9.4	7.1	2.3	9.8
Total		311.5	208.2	103.3	225.7	183.4	42.3	33.2	24.8	8.4	52.6
South Carolina 1977	Oak-pine	42.0	28.3	13.7	30.4	24.8	5.6	4.7	3.5	1.2	6.9
	Upland hardwood	102.5	71.7	30.8	77.5	62.4	15.1	12.4	9.3	3.1	12.6
	Lowland hardwood	8.3	6.5	1.8	6.4	5.3	1.1	1.4	1.2	.2	.5
Total		152.8	106.5	46.3	114.3	92.5	21.8	18.5	14.0	4.5	20.0
North Carolina 1975	Oak-pine	57.3	37.8	19.5	42.9	35.0	7.9	3.7	2.8	.9	10.7
	Upland hardwood	205.4	140.5	64.9	155.7	126.0	29.7	19.1	14.5	4.6	30.6
	Lowland hardwood	31.8	23.3	8.5	23.7	19.8	3.9	4.6	3.5	1.1	3.5
Total		294.5	201.6	92.9	222.3	180.8	41.5	27.4	20.8	6.6	44.8
Virginia 1976	Oak-pine	39.8	25.1	14.7	27.5	22.3	5.2	3.8	2.8	1.0	8.5
	Upland hardwood	260.2	181.5	78.7	195.2	158.2	37.0	30.9	23.3	7.6	34.1
	Lowland hardwood	13.5	10.1	3.4	9.8	8.1	1.7	2.5	2.0	.5	1.2
Total		313.5	216.7	96.8	232.5	188.6	43.9	37.2	28.1	9.1	43.8
All States	Oak-pine	240.0	157.5	82.5	175.1	142.8	32.3	19.7	14.7	5.0	45.2
	Upland hardwood	703.7	482.8	220.9	524.0	423.6	100.4	78.7	59.2	19.5	101.0
	Lowland hardwood	128.6	92.7	35.9	95.7	78.9	16.8	17.9	13.8	4.1	15.0
Total		1,072.3	733.0	339.3	794.8	645.3	149.5	116.3	87.7	28.6	161.2

[a]Does not include biomass on NIPF lands leased to forest industry.
[b]Includes all stumps, tops, and limbs, plus total sapling weight.

Table [illegible]--Total growing-stock [illegible] on NIPF hardwood stands in the Southeast Piedmont, by species and diameter class

Species	All diameter classes	Diameter class											
		[illegible]	[illegible]	[illegible]	[illegible]	10	12	14	16	18	20	22-28	30+
	Million tons												
Southern yellow pines:													
Loblolly pine	[illegible]	.6	2.5	[illegible]	6.8	8.7	10.0	8.6	5.9	3.7	2.1	2.5	.2
Shortleaf pine	[illegible]	.7	2.2	6.3	10.2	10.1	[illegible]	[illegible]	1.8	1.0	.3	.1	--
Virginia pine	28.0	1.1	[illegible]	5.6	6.7	5.7	[illegible]	1.3	.5	.1	--	--	--
Other yellow pines	[illegible]	.1	.5	.6	.8	1.0	1.3	.9	.5	.2	.1	.2	--
Total yellow pines	135.0	2.5	9.0	17.9	24.5	25.5	[illegible]	[illegible]	8.7	[illegible]	[illegible]	2.8	.2
Other softwoods	[illegible]	1.2	1.7	1.9	1.5	1.3	1.0	1.0	.8	.9	.9	.4	.1
[illegible] softwoods	[illegible]	[illegible]	10.7	19.8	26.0	26.8	22.9	[illegible]	9.5	[illegible]	3.0	3.2	.3
Soft hardwoods:													
Sweetgum	92.3	6.3	9.8	[illegible]	[illegible]	14.0	12.5	8.5	6.4	3.6	2.3	2.9	.4
Yellow poplar	101.8	2.8	5.2	7.6	[illegible]	12.8	15.8	14.7	11.6	8.0	5.7	6.8	1.5
[illegible] and [illegible]	28.3	2.8	2.7	2.9	3.8	4.5	[illegible]	2.7	2.1	.9	.5	.9	.2
Bay and magnolia	3.9	[illegible]	.4	.5	.6	.5	.4	.6	.2	.1	.1	.1	.1
Soft maples	67.6	[illegible]	8.9	9.4	9.0	[illegible]	6.8	5.5	4.1	2.7	1.9	2.8	.6
Other soft hardwoods	[illegible]	2.5	[illegible]	3.8	4.2	[illegible]	[illegible]	[illegible]	2.4	1.5	1.0	2.2	.5
[illegible] hardwoods	326.3	21.2	30.6	36.5	40.2	44.8	43.8	35.1	26.8	16.8	11.5	15.7	[illegible]
Oaks:													
Black	[illegible]	.9	1.7	3.5	3.9	5.2	5.3	4.4	[illegible]	2.2	1.6	2.6	.4
Chestnut	[illegible]	.6	2.5	3.3	4.7	6.0	6.0	5.7	4.7	3.3	1.9	2.2	.5
Laurel	[illegible]	.8	1.1	1.1	1.0	1.2	.8	.7	.5	.5	.7	[illegible]	.6
[illegible] oak	[illegible]	1.0	1.2	2.9	3.0	[illegible]	4.6	[illegible]	[illegible]	3.0	[illegible]	[illegible]	.8
Scarlet	38.3	.7	1.8	[illegible]	5.8	5.6	6.3	[illegible]	3.9	2.5	[illegible]	1.5	.1
Southern red	[illegible]	2.0	[illegible]	[illegible]	4.6	5.1	5.6	4.5	[illegible]	2.3	1.5	[illegible]	.7
Water	25.4	1.6	2.5	[illegible]	3.2	3.2	[illegible]	2.1	2.0	1.6	.6	1.5	.2
White	126.2	[illegible]	6.7	12.0	14.1	18.1	[illegible]	[illegible]	13.8	7.8	5.5	8.5	2.2
Other oaks	[illegible]	[illegible]	2.8	[illegible]	5.5	[illegible]	5.9	[illegible]	[illegible]	2.4	1.7	[illegible]	1.0
Scrub oaks	10.1	1.3	2.0	2.2	2.0	1.2	.9	.3	.1	.1	--	--	--
Total Oaks	[illegible]	13.4	25.3	41.4	[illegible]	[illegible]	56.1	[illegible]	38.5	25.7	16.6	26.7	6.5
Other hardwoods:													
Ash	17.6	1.2	1.8	2.6	2.6	2.4	2.2	1.8	1.1	.8	.4	.6	.1
Hickory	[illegible]	[illegible]	6.5	7.9	9.1	10.5	10.8	9.5	7.9	5.0	[illegible]	3.8	.5
Other hard hardwoods	70.8	12.5	13.5	5.6	5.8	6.4	7.5	5.7	[illegible]	[illegible]	2.0	4.0	.5
Miscellaneous spp.	[illegible]	6.7	[illegible]	6.2	[illegible]	1.8	.7	.4	.2	--	.1	.1	--
[illegible] hardwoods	[illegible]	25.0	[illegible]	22.3	[illegible]	21.1	21.2	[illegible]	13.1	9.2	5.0	8.5	1.1
[illegible]	[illegible]	59.6	97.4	100.2	[illegible]	121.5	121.1	101.8	78.4	51.7	[illegible]	50.9	[illegible]
All species	1,072.3	[illegible]	98.1	120.0	[illegible]	148.3	[illegible]	117.3	87.9	57.6	36.1	[illegible]	11.2

[1]Does not include biomass on NIPF lands leased to forest industry nor stands classified as primarily pine.

Table 6.--Minimum stocking standards by diameter class, numbers of trees, and basal area for fully and medium stocked stands

D.b.h. class	Minimum number of trees per acre for--		Minimum basal area per acre for--	
	Full stocking	Medium stocking	Full stocking	Medium stocking
Seedlings	600	360	--	--
2	560	336	--	--
4	460	276	--	--
6	340	204	67	40
8	240	144	84	50
10	155	93	85	51
12	115	69	90	54
14	90	54	96	58
16	72	43	101	61
18	60	36	106	64
20	51	31	111	67

all age classes, fully stocked hardwood stands in the Piedmont are accumulating 15 percent more biomass per acre than medium stocked stands and over three times more biomass than poorly stocked stands.

These graphs originate at age 15 because many hardwood stands begin with some biomass in residual trees left when the previous stand was harvested. Data from stands younger than age 15 are heavily influenced by these residuals and were not included.

About 63 percent of all NIPF hardwood stands in the Piedmont are fully stocked, 33 percent medium stocked, and 4 pecent poorly stocked with all live trees. These percentages and the biomass production values associated with them suggest that biomass production could be increased by 15 to 20 percent if all stands were fully stocked. In reality, opportunities are much greater if growing-stock stocking is considered. Only 21 percent of NIPF hardwood stands are fully stocked with growing-stock trees, while 56 percent are medium stocked and 23 percent are poorly stocked. Obviously, there is much opportunity not only to increase total growth but also to shift this growth to more desirable trees.

Dividing accumulated tons of biomass per acre in each age class by the age-class midpoint yields a measure of annual biomass production (fig. 3). In both medium and fully stocked stands, annual biomass production peaks before age 15 and begins to fall sharply as tree crowns close and overall growth slows. Poorly stocked stands, disadvantaged from the start by lack of trees available to fix light energy, never experience this early surge of growth. These stands start out slowly and reach the apex of biomass production at about age 30.

Unlike percent stocking, site quality is expensive to improve. Nevertheless, it is important to know the full impact of site quality on timber growth. The majority of Piedmont stands occur on medium sites. Figures 4 and 5 depict the influence of site class on biomass accumulation and production. Performance of a particular stand will vary as a result of the treatment it receives, but there is much less shifting among site classes than among stocking levels.

As expected, site class also has a significant bearing on biomass accumulation (fig. 4). On the average, good sites accrue about 26 percent more biomass than medium sites and 48 percent more than poor sites across all ages. Stands on poor sites are not nearly as disadvantaged as stands that are poorly stocked. Figure 5 shows that stands on poor sites experience an early surge of growth, whereas poorly stocked stands do not (fig. 3).

Green weight of forest biomass on all NIPF commercial forest land supporting hardwood stands in the Piedmont averages 79.5 tons per acre. The weighted average age of these same stands is 43.1 years. By dividing average age into average weight we can determine that the average Piedmont hardwood stand is manufacturing over 1.8 tons, or nearly 3,700 pounds, of biomass per acre annually. Remember that these figures do not include any foliage, shrubs, vines, forbs, etc.

NIPF Hardwood Past Treatment

At each sample location, field crews recorded the primary past treatment or disturbance that had occurred during the latest remeasurement period. Results were separated by broad forest type and summed for all six Piedmont Survey Units. Since the remeasurement periods for the Piedmont averaged 10.9 years, one can assume that values reported represent conditions approximately 5.5 years after treatment. Also, they indicate the forest type at the time of the new inventory rather than at time of treatment.

Over the remeasurement period nearly 2.3 million acres of NIPF land in the Piedmont experienced a final harvest, were retained in commercial forest, and are now classed as hardwood types (table 7). Thus, the rate of final harvest (including clear-cutting, seed-tree cutting, salvage, and high-grading) averaged more than 207,000 acres annually, excluding commercial thinnings, other intermediate cutting, and land clearing. The residual green weight of forest biomass on these acres averaged 39.1 tons per acre (table 8). Much of the biomass left in the woods after final harvest is in rough, rotten, and small trees. The high proportion of residual biomass left in these hardwood stands indicates that many acres are still being high-graded. This practice must be curtailed if we are to stem the proliferation of low-grade hardwood stands. The poor-

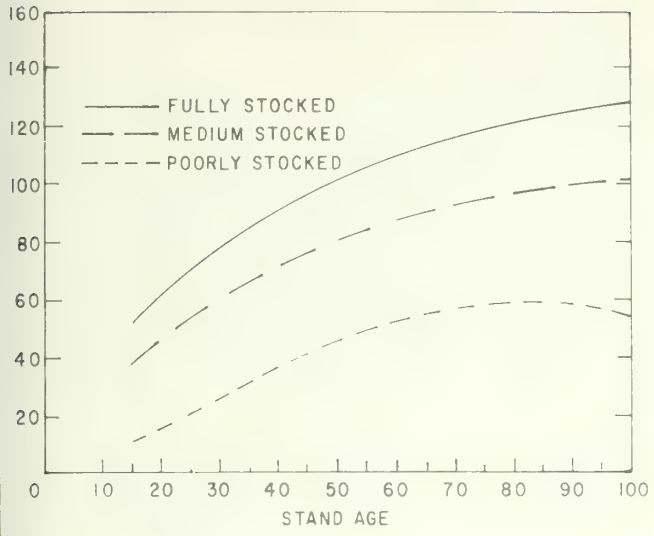

Figure 2.--Accumulation of biomass per acre, by stand age and stocking, on all NIPF hardwood stands, Southeast Piedmont (excluding Georgia).

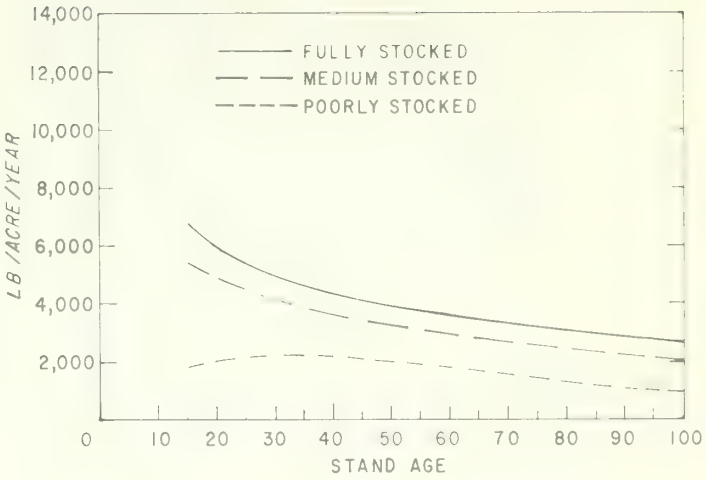

Figure 3.--Mean annual production of biomass per acre, by stand age and stocking, on all NIPF hardwood stands, Southeast Piedmont (excluding Georgia).

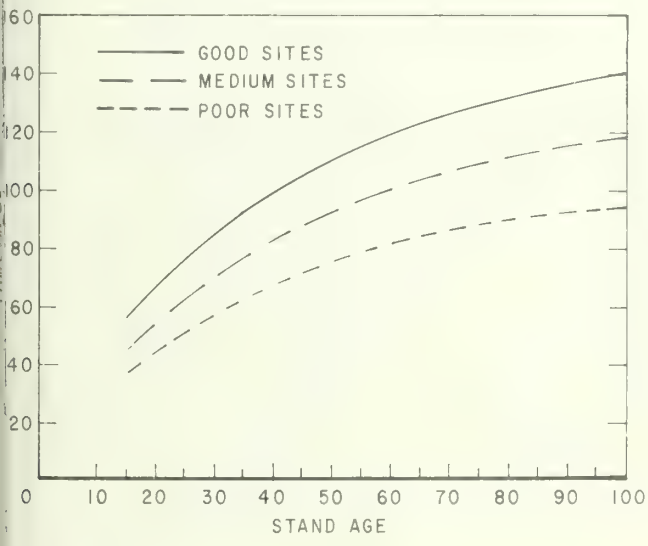

Figure 4.--Accumulation of biomass per acre, by stand age and site class, on all NIPF hardwood stands, Southeast Piedmont (excluding Georgia).

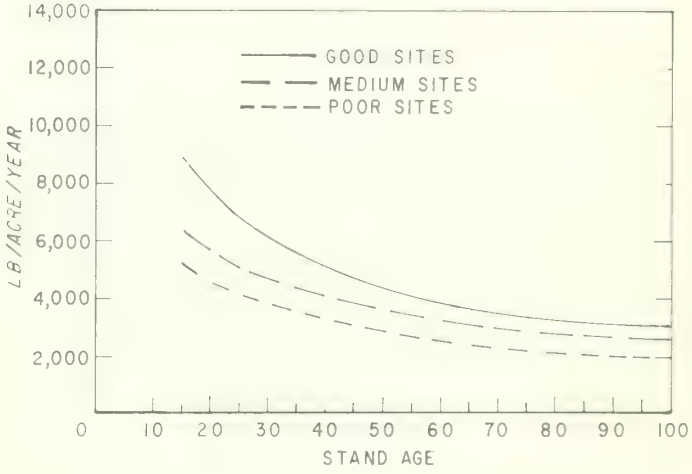

Figure 5.--Mean annual production of biomass per acre, by stand age and site class, on all NIPF hardwood stands, Southeast Piedmont (excluding Georgia).

Table 7.--Area of NIPF hardwood stands, by recent past treatment or disturbance and broad forest type, Southeast Piedmont

Recent past treatment or disturbance[a]	All types	Broad forest type		
		Oak-pine	Upland hardwood	Lowland hardwood
	Thousand acres			
Harvesting	2,257.0	533.6	1,532.5	190.9
Commercial thinning	296.6	112.0	145.3	39.3
Artificial planting	18.0	13.3	4.7	--
Natural disturbance	424.2	119.0	208.5	96.7
Other[b]	2,463.4	630.6	1,618.9	213.9
None	8,743.5	2,097.5	5,609.9	1,036.1
All stands	14,202.7	3,506.0	9,119.8	1,576.9

[a]Primary treatment or disturbance of the stand during latest survey interval in each State.

[b]Includes cleaning, release, draining, prescribed burning, site preparation, and other miscellaneous treatments.

Table 8.--Average green weight of forest biomass on NIPF hardwood stands, by recent past treatment or disturbance and hardwood broad forest type, Southeast Piedmont

Recent past treatment or disturbance[a]	All types	Broad forest type		
		Oak-pine	Upland hardwood	Lowland hardwood
	Tons per acre			
Harvesting	39.1	38.5	37.8	51.1
Commercial thinning	70.1	69.9	70.5	69.3
Artificial planting	21.6	29.2	0	--
Natural disturbance	75.2	78.7	73.4	74.9
Other[b]	76.2	70.5	78.4	75.9
None	85.0	75.0	87.9	89.4
All stands	75.5	68.4	77.2	81.6

[a]Primary treatment or disturbance of the stand during latest survey interval in each State.

[b]Includes cleaning, release, draining, prescribed burning, site preparation, and other miscellaneous treatments.

quality hardwood stands we observe today are not so much the result of poor sites or inherently poor tree form, but rather of the inferior trees left on the site after one or more harvest cuts. We cannot expect to produce fully stocked, high-quality hardwood stands when an average of 39.1 tons per acre of biomass remain on site after harvest in the form of rough and rotten cull trees and noncommercial understory saplings. Landowners should attempt to sell all trees when they make a timber sale, but where fuelwood markets are poor and firewood is too expensive to remove, sale may not be possible. In such cases, the residuals should be felled and left in the woods. Although this practice appears wasteful, the long-range benefits of establishing more valuable hardwoods far exceed the loss of underutilized biomass at the time of harvest.

Only 2 percent of all NIPF hardwood stands experienced a commercial thinning over the remeasurement period. On the average, these stands had about 15 tons per acre, or 18 percent of the biomass, removed from them. Relatively few hardwoods have been planted on NIPF land. The figures listed in tables 7 and 8 are most likely unsuccessful pine plantations which resulted in an oak-pine forest type. Natural disturbances and miscellaneous treatments occurred on 2.9 million acres of NIPF Piedmont timberland. These events reduced the average per acre forest biomass by about 10 tons.

Hardwood Utilization

Some people have expressed concern that harvesting forest biomass for energy or increased fiber production might aggravate hardwood procurement problems in the Piedmont. Estimates of Piedmont hardwood removals show that only 54 percent of all felled hardwood biomass (22.9 million tons) is used for roundwood products (table 9). Since it was not possible to isolate removals from only NIPF timberland for every item, the figures in table 9 include estimates of hardwood removals from all ownerships in the Piedmont. However, the NIPF ownership group holds such a high proportion of hardwood acreage in the Piedmont that ratios developed from table 9 are heavily influenced by harvesting practices on NIPF land. Also, a fraction of the hardwood biomass shown here came from pine stands.

Industrial products, along with the weight of hardwood biomass harvested for fuelwood, constitute the estimate of all roundwood products. Traditionally, the merchantable volume of a tree has been defined as that portion between a 1.0-foot stump and a 4.0-inch d.o.b. top, including all forks greater than 4.0 inches d.o.b in trees 5.0 inches and larger. Logging residues are the merchantable portions of felled trees remaining in the woods after harvest. Logging slash is the weight of wood and bark in felled-tree stumps less than 1.0 foot above ground, in felled-tree tops between 4.0 inches and 0.5 inches d.o.b., and in all felled saplings not used for timber products. Other removals include the unused total-tree biomass of all hardwoods destroyed in land clearing and cultural operations. Between 1971 and 1976, an average of 12 percent of the total annual felled weight of hardwood biomass in the Piedmont remained in the woods as logging residues; 17 percent remained as logging slash, and 17 percent as unused other removals.

During most harvest operations, some trees are judged worthless by the logger and bypassed because of size, species, or quality (Welch 1980). On NIPF land in the Piedmont, some 39 tons per acre of these living residues were left in the woods following final harvest. Generally these living remnants, although counted as part of the timber resource, inhibit the development of new stands. At least 7.4 million tons of hardwood biomass accumulated annually as obstructive living residues on commercial forest land in the Piedmont between 1971 and 1977 (table 9).

Other standing residues are those trees which were once part of the commercial forest but, because of land clearing for agricultural, urban, or some other land use, now stand in a nonforest condition. In many instances, these trees are beneficial because they encourage wildlife, have esthetic value, provide shade, or reduce erosion and siltation. In any case, they do not inhibit the establishment of new stands on existing timberland. About 2.9

Table 9.--Total green weight of annual removals of all hardwood live timber on all ownerships by item, State, and year, Southeast Piedmont

Item	All States	State and year			
		Georgia 1971	North Carolina 1973	South Carolina 1977	Virginia 1976
		Million tons			
All roundwood products[a]	12.3	3.2	3.3	1.6	4.2
Logging residues[b]	2.7	.7	.8	.3	.9
Logging slash[c]	3.9	1.2	1.0	.5	1.2
Other removals[d]	4.0	1.1	1.3	.6	1.0
Total felled weight	22.9	6.2	6.4	3.0	7.3
Commercial forest living residues[e]	7.4	2.6	1.8	1.3	1.7
Removed from commercial forest[f]	2.9	.8	1.0	.3	.8
Total standing residues	10.3	3.4	2.8	1.6	2.5
Total all	33.2	9.6	9.2	4.6	9.8

[a]Green weight of merchantable and unmerchantable portions of all live hardwoods 5.0 inches d.b.h. and larger, plus all hardwood saplings used to produce all roundwood products.

[b]Green weight of merchantable portions of all live hardwoods 5.0 inches d.b.h. and larger destroyed and not utilized during harvest operations.

[c]Green weight of unmerchantable portions of all live hardwoods 5.0 inches d.b.h. and larger, plus all hardwood saplings destroyed and not utilized during harvest operations.

[d]Total green weight of all live hardwoods 5.0 inches d.b.h. and larger, plus all hardwood saplings destroyed and not utilized during cultural operations and land clearing.

[e]Total green weight of all live hardwoods 5.0 inches d.b.h. and larger, plus all hardwood saplings still standing in commercial forest on acres which experienced a final harvest.

[f]Total green weight of all live hardwoods 5.0 inches d.b.h. and larger, plus all hardwood saplings still standing but no longer in a forest condition.

illion tons of hardwood biomass were dded to this category annually (table 9). When both standing and felled residues re considered, only 37 percent of the ardwood biomass in harvested stands is eing utilized. The remaining 63 percent s left in the woods because, to date, oggers have not been able to make these esidues pay their way out of the woods. his situation may be changing. Cur-ently, hardwood whole-tree chips bring n average delivered pulpwood price of $12 er green ton in the Piedmont (Timber art-South 1982). Based on cost com-arisons with No. 2 fuel oil, the Office f Technology Assessment has estimated hat economic conditions in the fore-eeable future suggest that wood energy sers could afford to pay up to $90 per ry ton of wood delivered, or about $45 er green ton (U.S. Congress 1980). Even f the value of this wood waste does not uadruple, the potential for increased alue along with the magnitude of the esource clearly indicates substantial conomic opportunity. In addition to the otential delivered value of logging waste nd living residues, the removal of these aterials from the forest would substan-ially reduce the landowner's cost of site reparation and replanting.

It is not reasonable to expect that all arvested biomass can or should be uti-ized. The economic, ecological, and ocial impacts of total utilization are omplex and differ greatly with local ituations. If hardwood stands in the iedmont were properly harvested, however, he product output from the hardwood esource could at least be doubled with no hreat to conventional hardwood supplies. ith proper regeneration and maintenance fter harvest, increased yields of better uality hardwoods are certain.

ardwood Treatment Opportunity

As long as vegetative cover is present, iomass will be produced. It is the task f the forest manager to maximize and hannel this growth onto the most benefi-ial species that circumstances permit. n 14 million acres of NIPF in the iedmont, hardwood management is a logi-al choice because it can produce good returns at much lower costs than pine management, and because it can provide the multiple benefits many small landowners desire. As the hardwood resource on NIPF land plays a role of increasing importance, it becomes critical that this resource be managed more productively.

In contrast to pine management, hardwood silviculture need be neither expensive nor intensive. Although research on hardwood management in the Piedmont has been rather limited, results applicable to the Piedmont are available from other regions of the country (Kellison, Frederick, and Gardner 1981; McGee, Beck, and Sims 1979; McGee and Hooper 1970). Several silvicultural options available to the hardwood manager at minimal cost are:

1. After final harvest, clearcut all residuals 1.0 inch d.b.h. and larger. Residuals need to be removed because they do not respond favorably to release after being in the understory so long; they shade out new sprouts and seedlings, and the stumps of these small stems prove to be the best sprouters. Salvage the residuals for firewood where possible but, even if the wood is not recoverable, fell the stems so a new vigorous even-aged stand can begin.

2. Strive to maintain full stocking. This condition is easily achieved at harvest by applying proper regeneration techniques; it is much more difficult to increase the stocking of established stands. Landowners should have their stands assessed for natural regeneration potential. Some of the better oak stands, with most of the stems larger than 15 inches d.b.h., will not regenerate naturally because the stems do not sprout. In these stands, enrichment plantings may be needed to obtain full stocking. Fortunately, most hardwood stands do not need enrichment plantings. Sprouts from small stumps, and seeds that remain viable in the soil litter for long periods of time, normally provide sufficient regeneration.

3. Deadening of undesirable species may be helpful on certain sites where strong competition from unwanted species will severely restrict or eliminate desirable species. Landowners should

weigh the cost of treatment against the probable improvement of species composition. They should be reminded that many undesirable species will drop out through natural mortality as the stand develops. Discretion should be used so that a tree is not killed where no other tree is available to occupy the site.

4. In fully stocked or overstocked stands, thinning and timber stand improvement (TSI) cuts are possibilities. At present, these operations are economical only where a heavy thinning is possible and markets are favorable. In the future, it is hoped the biomass removed in light thinnings and TSI operations will return enough revenue to offset operating costs. Landowners should be reminded that returns from management efforts are usually greatest on the best sites and that all stands do not need treatment. Some young stands just need time to develop on their own.

If NIPF owners would apply some of the treatments suggested here and put their land under management, several important benefits would logically follow. In the short run, the demand for energy wood and some other products would be met through the conversion of poor-quality stands to young, vigorous stands. In the long run, the hardwood resource would be improved in both quantity and quality; landowners would make more profit from timber sales; and some of the demand pressure now placed on southern pines could be relieved.

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KEYWORDS: Nonindustrial private forest land, forest trends, hardwood forest land, Piedmont forest land, forest biomass, hardwood timber volume, hardwood silviculture.

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Research Paper
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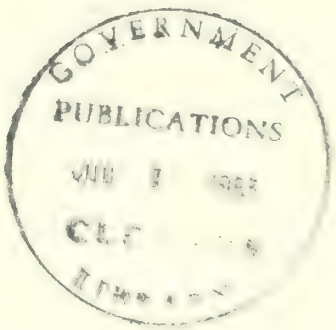
Legumes in Forestry: Results of Adaptability Trials in the Southeast

by
Jacques R. Jorgensen
and
Joseph R. Craig



March 1983
Southeastern Forest Experiment Station
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Legumes in Forestry: Results of Adaptability Trials in the Southeast

by

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Abstract.--More than 50 species of nitrogen-fixing plants were sown on one or more sites. A number of fertilizer treatments, none of which included nitrogen, were used. Only eight perennials and six annuals persisted for more than two growing seasons. Subterranean clover was the most promising annual and sericea lespedeza the most promising perennial tested. The majority of the plant failures were related to physical or chemical properties of soil. Browsing, especially on small plots, was an important factor in limiting the growth and establishment of plants that produced palatable forage.

Keywords: Cover crops, forest soils, nitrogen fixation, Lespedeza cuneata, Lespedeza thunbergii, Lotus corniculatus, Lotus pedunculatus, Trifolium subterraneum.

There are about 18,000 species of leguminous plants, most of which can fix, or convert, atmospheric nitrogen (N_2) to a form that can be assimilated by plants. In addition, there are about 160 species of nonleguminous plants that have the same capacity. These N-fixing plants are found in highlands and lowlands, temperature zones and the humid tropics, and from deserts to aquatic habitats. Their basic growth requirements--carbon dioxide, oxygen, light, water, nutrients--are the same as for other plants; however, the quantities required for growth vary greatly. Some species are demanding, whereas others are able to survive, grow, and reproduce on a bare minimum. These latter plants, able to survive, grow, and fix N under adverse conditions, are best adapted for use in forestry.

The capacity to fix N varies greatly among species. Some tropical legumes can add as much as 500 kg/ha of N to the soil annually (Natl. Acad. Sci. 1977). Under agricultural conditions, legumes are capable of fixing up to several hundred kg/ha of N annually. Fixation under forest conditions is usually less than in agriculture, but substantial quantities of N can be added over a period of years. In the Pacific Northwest, snowbrush (*Ceanothus velutinus* Dougl. and *C. velutinus* var. *laevigatus* T. & G.), nonleguminous shrubs have added an average of 90 kg/ha of N annually over a 10-year period (Youngberg and Wollum 1976). Stands of red alder (*Alnus rubra* Bong.) growing in the same region have increased site N by 320 kg annually over a 15-year period (Newton and others 1968). In fully stocked forest stands, where N-fixing plants may occur primarily in the understory, N fixation, at best, probably averages only a few kg/ha annually. Low fixation in these stands is directly related to biomass production, a consequence of the environment.

An investigation of N-fixing plants that improve the forest environment could take one or both of two approaches: utilize native plants adapted to the habitat, or utilize agronomically important N-fixing plants. Agronomic plants were chosen for this study because the seed are commercially produced, the plants' requirements for

growth and N-fixation are known, and there is information on the quantity of N they are capable of fixing.

Where possible, plant nomenclature followed Fernald (1970) and Terrell (1977). Nomenclature not included in these references was obtained from the Soil Conservation Service and from recent literature.

Methods

Reported here are initial observations of the adaptability of N-fixing plants to forest conditions. Beginning in 1976, in cooperation with forestry-oriented organizations, a series of plots were established to determine the capability of N-fixing plants to grow and maintain themselves on soils usually more suitable for forestry than for agriculture--that is, infertile, acid soils. These trials were located primarily in the lower Coastal Plains of Virginia, North Carolina, and South Carolina, and in the Piedmont of North Carolina and Virginia.

Initial trials emphasized the selection of adapted species and their soil fertility requirements. The first species eliminated were those that required lime and potassium (K) in addition to phosphorus (P) for satisfactory growth. Other selection factors were ease of stand establishment, competitive ability, reseeding capacity (if an annual), disease resistance, and ability to withstand browsing.

In these studies, seed of 52 selected species and varieties of N-fixing plants were sown in well-prepared, freshly disked seedbeds with fertilization regimes that ranged from none to 224 kg/ha of P, 116 kg/ha of K, and 2,240 kg/ha of dolomitic limestone (L). However, most fertilizer applications were from 50 to 100 kg/ha of P added as ground rock phosphate or triple superphosphate. No fertilizer N was added at any time. In a few instances, the minor elements molybdenum and cobalt were applied to determine whether they were needed to enhance the N-fixation process. Seed were treated with an appropriate inoculum before planting.

For promising species such as subterranean clover, several cultivars were tried and more than 70 trials (the product of fertilization X seeding rates X number of sites X number of cultivars) were carried out with this species. For the majority of plants, seed availability limited testing to one or two cultivars and fewer trials. Most species were tried in more than one location and with several fertilizer regimes before trials were discontinued.

Although plots varied in size, depending on availability of space and seed, they usually fell into two groups: plots larger than 30 m^2 or smaller plots that ranged downward to a meter or two per row. In all instances, plants that established successfully were tested on large plots in addition to initial screening done on small plots. Statistical designs ranged from completely randomized blocks to split-plot blocks. Most installations were replicated three times.

Results and Discussion

The majority of all species failed either to become established initially or, if annuals, to reestablish themselves for the second growing season (tables 1, 2). Of the 52 species, only 6 annuals--Kobe lespedeza, Korean lespedeza, partridge pea, rose clover, crimson clover, and subterranean clover, and 8 perennials--tickclover, false anil indigo, bicolor lespedeza, sericea lespedeza, Thunberg lespedeza, virgata lespedeza, birdsfoot trefoil, and big trefoil persisted for more than two growing seasons in any one of several trials. These trials sometimes included fertilization with K and lime, a system generally not economical for forestry use.

Subterranean clover was the most promising annual tested, although there were differences among the eight cultivars examined. 'Mt. Barker', a commonly planted midseason variety, and 'Tallarook', a late variety, were the best adapted and most extensively tested. Under favorable conditions, these varieties produced volunteer stands for

Table 1.--Nitrogen-fixing plants that have established successfully for 1 or more years in the field.

No. of trials & soil series	Fertilizer[a]	Years of success[b]	Comments[c]
CASSIA FASCICULATA Michx.--partridge pea			
2, Chipley	None, PKL	2+	--
DESMODIUM PANICULATUM (L.) DC--tickclover			
3, Chipley	None, PKL	2+	--
1, White Store	112 P (G) + K	3+	--
INDIGOFERA PSEUDOTINCTORA Matsum.--false anil indigo			
1, Creedmore	PKL	4+	o
1, White Store	None	4+	o
LESPEDEZA BICOLOR Turcz.--bicolor lespedeza			
4, Chipley	None to PKL	2+	--
LESPEDEZA CUNEATA (Dum.) G. Don--sericea lespedeza			
4, Chipley	None to PKL	2+	--
1, Georgeville	None	1	b,g
2, Georgeville	27, 54 P (T)	3+	o
1, Goldsboro	None	2	--
1, Goldsboro	89 P (G)	5+	--
2, White Store	None, PKL	4+	--
'Appalow' cultivar			
1, Chipley	PKL	2+	--
1, White Store	54 P (G)	2+	--
LESPEDEZA STIPULACEA Maxim.--Korean lespedeza			
3, Georgeville	*None, 27, 54 P (T)*	*1*	*n*
1, Goldsboro	*None*	*0*	--
1, Goldsboro	*89 P (G)*	*1*	*1*
1, White Store	*None*	*1*	--
1, White Store	*PKL*	*4+*	--
LESPEDEZA STRIATA (Thunb.) H.&A.--Kobe lespedeza			
4, Chipley	None, PKL	2	j
1, White Store	54 P (G)	1	g
1, White Store	None, PKL	4+	--

Continued

Table 1.--Nitrogen-fixing plants that have established successfully for 1 or more years in the field--continued

No. of trials & soil series	Fertilizer[a]	Years of success[b]	Comments[c]
LESPEDEZA THUNBERGII (DC.) Nakai--Thunberg lespedeza cv. 'VA-70'			
2, Chipley	None, PKL	2+	--
1, Goldsboro	None	2	q,a
1, Goldsboro	89 P (G)	5+	a
4, White Store	None, PKL	2+,4+	o
LESPEDEZA VIRGATA DC.--virgata lespedeza cv. 'Ambro'			
3, Chipley	None, PKL	2+	q
1, Georgeville	None	1	b,q
2, Georgeville	25, 54 P (T)	3+	q
2, White Store	None, PKL	4+	o
1, White Store	54 P (G)	2+	--
LOTUS CORNICULATUS L.--birdsfoot trefoil cv. 'Viking', 'Empire'			
4, 'Sand','loam'	None	0	--
'Granger' cultivar			
1, White Store	56 P (G)	3+	--
LOTUS PEDUNCULATUS Cav.--big trefoil cv. 'Marshfield'			
2, Norfolk	None, PKL	0	f,i
2, Norfolk	44 P (T), 88 P (G)	4+	k,i,o
1, White Store	56 P (G)	2+	--
TRIFOLIUM CAMPESTRE Schreb.--large hop clover			
1, Norfolk	None	0	b
2, Norfolk	44 P, 88 P	1	--
1, Norfolk	PKL	2	q,m
1, White Store	None	0	--
1, White Store	PKL	1	--
2, Woodington	None, 56 P (T)	0	b
TRIFOLIUM DUBIUM Sibth.--small hop clover			
1, Norfolk	PKL	1	q,m
3, Norfolk	None, 44 P, 88 P	0	b,f
1, White Store	None	0	b
1, White Store	PKL	1	--

Continued

Table 1.--Nitrogen-fixing plants that have established successfully for 1 or more years in the field--continued

No. of trials & soil series	Fertilizer[a]	Years of success[b]	Comments[c]
TRIFOLIUM HIRTUM All.--rose clover cv. 'Hykon', 'Kondinin'			
7, Cecil, White Store	None, PKL	0	b
2, Norfolk	None, 56 P (G)	0	b
1, Norfolk	PKL	4+	--
TRIFOLIUM INCARNATUM L.--crimson clover cv. 'Dixie', 'Tibbie'			
3, Cecil	None to PKL	0	c,e
2, Norfolk	None	0	b
4, Norfolk	Various P	1	b,g,k
1, Norfolk	PKL	2	b,g,f
1, White Store	None	0	--
1, White Store	PKL	2+	--
12, Woodington, Rains	None to 224 P (T)	0	a,b,d
TRIFOLIUM NIGRESCENS Viv.--ball clover			
11, Cecil, Woodington, Norfolk	None to PKL	0	a,b,c,f
1, Norfolk	PKL	2	--
TRIFOLIUM RESUPINATUM L.--Persian clover cv. 'Albon'			
1, Norfolk	PKL	2	--
6, Woodington, Rains	None to 112 P	0	a,b,d
TRIFOLIUM SUBTERRANEUM L.--subterranean clover cv. 'Mt. Barker'			
3, Cecil,	None to PKL	0	e
3, Lakeland	None to PKL	0	c
3, Norfolk	None	0	b
1, Norfolk	None	1	b,k
3, Norfolk	44 P (T), 88 P (G)	2	g,k,m
1, Norfolk	56 P (G)	1	b,m
5, Norfolk	56 P (G,T), 112 P (G), 224 P (G)	3+	k
1, Norfolk	PKL	4+	--
3, Rains	None to 112 P (T)	0	b,d,h
5, Rains	112 P (G) to PKL	1	d,g,k
2, White Store	88 P (T), PKL	1	k
4, Woodington	None to 224 P (T)	0	b
1, Woodington	112 P (G)	1	b,m

Continued

Table 1.--Nitrogen-fixing plants that have established successfully for 1 or more years in the field--continued

No. of trials & soil series	Fertilizer[a]	Years of success[b]	Comments[c]
'Tallarook' cultivar			
1, Norfolk	None	1	b,k
6, Norfolk	56 P (G,T) to 224 P (G)	3+	g,k
1, White Store	112 P (G) + K	1	k
1, Woodington	56 P (T)	0	b
'Yarloop' cultivar			
2, Rains	112 P (T)	0	b,d
5, Rains	112 P (G) to PKL		--
1, White Store	112 P (G,T) + K	1	k
2, Woodington	None, 56 P (T)	0	b
'Wooqenellup' cultivar			
2, Woodington	None, 56 P (T)	0	b
'Dinninnup', 'Dwalganup', 'Geraldton', 'Seaton Park' cultivars			
20+, Lakeland, Norfolk, White Store, Woodington	None to PKL	0-1	b,c,f,q,h,k
TRIFOLIUM VESICULOSUM Savi--arrowleaf clover cv. 'Meechee'			
3, Cecil	None to PKL	0-1	l,j
6, Norfolk	None to 224 P (G)	1	l,j
4, Rains	None to 112 P (G,T)	0	--
1, White Store	None	1	--
1, White Store	PKL	2	--
4, Woodington	None to 224 P (T)	0	b
1, Woodington	112 P (G)	1	b
'Yuchi' cultivar			
3, Cecil	None to PKL	0-1	--
3, Norfolk	None	0	b
6, Norfolk	44 P (T) to PKL	1-2	j
2, Woodington	None, 56 P (T)	0	b

Continued

Table 1.--Nitrogen-fixing plants that have established successfully for 1 or more years in the field--continued

No. of trials & soil series	Fertilizer[a]	Years of success[b]	Comments[c]
VICIA VILLOSA Roth--hairy vetch			
2, Cecil	None, 56 P (T)	0	--
1, Cecil	PKL	1	--
2, Norfolk	None	0	b
4, Norfolk	44 P (T) to PKL	1	--
1, White Store	None	0	b
1, White Store	PKL	1	b
2, Woodington	None, 56 P (T)	0	b

[a] kg/ha of element. Phosphorus source (G) = ground rock phosphate, (T) = triple superphosphate. PKL = P 56 to 112 kg/ha, K 56 kg/ha, lime (L) 2,240 kg/ha (usual rate).

[b] Number of years in which plant successfully grew or reestablished itself. A + indicates test is continuing or had established plants when last examined.

[c] Comments:

(a) Poor initial establishment.
(b) Soil nutrient deficiencies.
(c) Drought problems.
(d) Excess moisture problems.
(e) Poor soil physical conditions.
(f) Plant poorly adapted to site.
(g) Severe competition.
(h) Cold damage.
(i) Poor initial growth.
(j) Poor reseeding following initial planting.
(k) Browsing and/or seed loss.
(l) Disease.
(m) Inoculation failure.
(n) Coarsely ground rock phosphate fertilizer.
(o) Established plants compete vigorously, but number may be insufficient for an adequate stand.

Table 2.--Nitrogen-fixing plants that did not establish successfully or have had poor growth or stand development over a period of 1 year or less.

Species	Common name	Comment[a]
ASTRAGALUS CICER L.	Cicer milkvetch	a,f
FALCATUS Lam.	Sickle milkvetch	a
GLYCYPHYLLOS L.	Milkvetch	f
CEANOTHUS AMERICANUS L.	New Jersey tea	a
CROTALARIA PALLIDA Ait.	Smooth crotalaria	a,f
LATHYRUS LATIFOLIUS L.	Perennial pea	a,f
LUPINUS ALBIFRONS Benth.	Foothill lupine	e,f,l
ALBIFRONS var. *DOUGLASSI* Agardh		e,f,l
ALBUS L.	White lupine	e,f,l
ANGUSTIFOLIUS L.	European blue lupine	e,f,l
ARBOREUS Sims	Tree lupine	e,f,l
HIRSUTUS L.		e,f,l
LUTEUS L.	European yellow lupine	e,f,l
NANUS Dougl.	Pygmy lupine	e,f,l
PALAESTINUS Boiss.		e,f,l
PERENNIS L.		a
PILOSUS Murray		e,f,l
PUBESCENS Benth.		e,f,l
RETICULATUS Desv.		e,f,l
VARIUS L.		e,f,l
MEDICAGO TRUNCATULA Gaertn.	Barrelclover	a,b,f
ORNITHOPUS SATIVUS Brot.	Serradella	b,c
PISUM SATIVUM L.	Field pea	b,j
TRIFOLIUM AMBIGUUM Bieb.	Kura clover	h
CHERLERI L.		a
FRAGIFERUM L.	Strawberry clover	h
PRATENSE L.	Red clover	h
REPENS L.	White clover	b,h
VICIA BENGHALENSIS L.	Purple vetch	b,h
DASYCARPA Ten.	Woollypod vetch	b,h
GRANDIFLORA Scop.	Big flower vetch	b,h,j,k
VIGNA RADIATA (L.) Wilczek var. *RADIATA*	Mung bean	k

[a] Fertilization usually consisted of a P + K + lime treatment on one or more soils. For key to letters, see table 1.

three or more seasons. The dense vegetation mat that developed from the dead subterranean clover plants in the late spring inhibited most annual weeds. However, perennials such as broomsedge (*Andropogon virginicus* L.) and dog fennel [*Eupatorium capillifolium* (Lam.) Small]--once established and with fertilizer P and biologically fixed N--eventually interfered with stand regeneration. Earlier maturing cultivars, such as 'Seaton Park' and 'Geraldton', did not produce enough biomass to inhibit the weed growth during the late spring and early summer, and weeds interfered with the reestablishment of these varieties in early fall.

When adapted subterranean clover varieties were planted on fertilized sites, the major cause of volunteer stand failure was browsing by deer and other animals. Browsing usually did not kill the legumes or prevent them from setting seed, but it severely reduced the amount of standing biomass at the end of the growing season. The low legume biomass was ineffective in suppressing weed seed germination and growth. Also, the unbrowsed weeds had a growth advantage, and they grew at the expense of the subterranean clover. Since most plots were small, one-fourth acre or less, animals concentrated in these areas for forage. It is not known whether plantings could be reasonably increased in size to reduce severity of damage by the animals, or whether they simply would attract more animals from a wider area. In some instances, subterranean clover planted on small plots failed to regenerate because seed were eaten by rodents.

The annual lespedezas, Korean and Kobe, persisted over 2 years in only 2 of 13 trials. In those successful trials, P, K, and lime fertilizers were used. Failures were associated with disease problems. Apparently these annuals are not as tolerant of soil conditions as the perennial lespedezas because they require lime and K in addition to P for good growth.

Partridge pea performed well in both trials, but Halls and others (1970) found that it did not reestablish well. Since this plant provides valuable seed for wildlife, further trials to determine its needs for regeneration are appropriate.

Crimson clover failed in 23 of 24 trials. Growth was poor under the fertilizer regime used and on the sites it was planted. The plant was a favorite for browsing and did not recover sufficiently to set much seed after browsing. This plant should be used for cover and N-fixation only when soils have relatively high fertility and are not extremely acid.

Rose clover grew and persisted well on the sandy, well-drained Norfolk soil but failed on heavier or less well-drained series. However, it required K, lime, and P for stand maintenance, and does not appear to have many advantages over subterranean clover, which is more tolerant of site deficiencies.

Thus far, sericea lespedeza has been the most widely planted and most successfully established perennial. Stands have been established with as little as 5.6 kg/ha of seed sown on the soil surface with burning as the only site preparation (Jorgensen and Davis 1983). Sericea is very competitive and eliminates most annual and perennial weeds. On phosphorus-deficient soils, P fertilization is necessary for sericea to compete against persistent weeds such as broomsedge. A higher level of soil P was required for lespedeza than was required for good growth of loblolly pine.

Thunberg lespedeza, like sericea, can eliminate most annual and perennial weeds by its dense growth once stands are established. Its advantage over sericea is that it is an excellent wildlife plant, providing seed and some browse. However, seed are expensive, not readily available, and some varieties, under certain conditions, can overtop and reduce the growth of young pines.

The perennial trefoils are still being investigated to determine whether they can be grown under forest conditions. Early studies with birdsfoot trefoil cultivars 'Viking' and 'Empire' were not encouraging. The cultivar 'Granger' was established at a later date and was found to be more tolerant.

Initial plantings of big trefoil resulted in few established plants. However, the surviving plants grew and competed well with perennial weeds for 4 years, the time the last examination was made. Recent plantings have shown that although early losses of small plants may be high, the remaining plants grow well and stands increase in density with time. Established trefoil stands have been damaged by insects and disease but, thus far, this has not prevented their regrowth the following year. Further work on both species of trefoils is continuing.

Limited trials of tickclover and false anil indigo have shown that the plants are tolerant of adverse soil conditions and can compete with native vegetation. Tickclover, however, is susceptible to defoliation by Japanese beetles (*Popillia japonica* Newm.), which could reduce the plants' ability to survive over the long term. There is no published information on quantity of N fixed by these plants under forest conditions, although some desmodiums have been recommended for cover crops in the past.

Bicolor lespedeza grew well in all plantings. It is a very desirable wildlife plant but does not appear to be suitable for general forest plantings. It grows as a tall woody shrub and can interfere with initial tree growth and survival and make later management operations difficult.

Although there are many reasons for the failure of N-fixing plants to become established, the majority are related to the physical or chemical properties of soil. These soil-site factors influenced the growth of most species, although the most tolerant plants grew and survived even on the poorer sites. Plants termed "failures" on poor sites with limited fertility may have succeeded on more productive soils or with additional soil amendments and protection.

In addition, some species had other major shortcomings. Stands of the annual lespedezas were sometimes defoliated by mildews before much seed was set. Root diseases killed most of the lupines planted on White Store soil and greatly reduced the growth of arrowleaf clover on several sites. For species adapted to the site and able to grow under moderate nutrient stress, browsing was the major factor that prevented the development or reestablishment of stands. Subclover, crimson clover, and the vetches were especially affected by browsing.

Conclusions

Relatively few N-fixing plants were capable of establishing and maintaining themselves on acid, nutrient-poor forest soils or with P fertilization only. Of the eight perennial and six annuals that persisted for more than 2 years, the annual, subterranean clover, and the perennials, sericea and Thunberg lespedezas, appeared best adapted to the wide range of forest sites in the Southeast. On phosphorus-deficient sites, P fertilization is necessary for the sustained growth of the N-fixing plants, enabling them to compete with native vegetation. Future work may identify superior species for general use or species that are better adapted to specific sites.

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Legumes in forestry: results of adaptability trials in the Southeast. Res. Pap. SE-237. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1983. 11 p.

More than 50 species of nitrogen-fixing plants were sown on one or more sites. A number of fertilizer treatments, none of which included nitrogen, were used. Only eight perennials and six annuals persisted for more than two growing seasons. Subterranean clover was the most promising annual and sericea lespedeza the most promising perennial tested. The majority of the plant failures were related to physical or chemical properties of soil. Browsing, especially on small plots, was an important factor in limiting the growth and establishment of plants that produced palatable forage.

Keywords: Cover crops, forest soils, nitrogen fixation, Lespedeza cuneata, Lespedeza thunbergii, Lotus corniculatus, Lotus pedunculatus, Trifolium subterraneum.

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